Journal

of the

British Interplanetary Society

Volume 8

1949

Published by
The British Interplanetary Society
London

The BRITISH INTERPLANETARY SOCIETY

(Limited by Guarantee)

Secretarial Address: 157 Friary Road, London, S.E.15

COUNCIL - 1949

A. V. CLEAVER (*Chairman*)

E. BURGESS
A. C. CLARKE, *B.Sc.*
P. E. CLEATOR
K. W. GATLAND
J. HUMPHRIES, *B.Sc.* (*Eng.*), *A.M.I.Mech.E.*, *A.F.R.Ae.S.*
T. R. F. NONWEILER, *B.Sc.*
H. E. ROSS
L. R. SHEPHERD, *B.Sc.*, *A.Inst.P.*
DR. A. E. SLATER, *M.A.*, *F.R.Met.S.*
R. A. SMITH
G. V. E. THOMPSON, *B.Sc.*, *A.R.C.S.*, *A.R.I.C.*

Technical Director: L. R. SHEPHERD, *B.Sc.*, *A.Inst.P.*

Secretary: L. J. CARTER, *F.R.S.A.*, *A.C.I.S.*

Auditor: T. W. WOODS, *A.S.A.A.*, *A.C.I.S.*

Opinions expressed in signed articles are those of the contributors and do not necessarily reflect the views of the Council of the Society unless such is expressly stated to be the case.

All material contained in this Journal is protected by copyright. Permission for reproduction may be granted only on written application to the Secretary of the Society.

Journal
of the
British Interplanetary Society

Vol. 8 No. 1 XXVI January, 1949

ORBITAL BASES

By H. E. Ross

(*A paper read to the British Interplanetary Society in London on November* 13, 1948.)

The advent of powerful military rockets is certainly a useful step forward in the progress of astronautics, but it still leaves the Moon a long way off in space—and perhaps in time. It would seem that rocket drive in one form or another will be used but no one yet knows how soon a sufficiently potent technique will emerge to provide us with the key to interplanetary travel. On the other hand, we should bear in mind that certain proposals have been advanced which, superficially at least, promise to make the requirements of a round trip to the Moon much less exacting than the commonly accepted *modus operandi* envisages. I refer in particular to the reduction in overall energy requirements which occur if, instead of postulating a journey direct to the surface of the satellite and back again, we consider splitting up the voyage into easy stages and refuelling our ships in space. As I shall presently attempt to show, a specific variant of this general conception does in fact materially improve the prospect of reaching the Moon without being forced to contemplate building and projecting one enormous vessel—although, even so, it would seem that some mild version of atomic power would still be needed for the drive. On the other hand unfortunately, several new difficulties arise with any method that involves refuelling in space, chiefly enhanced problems of precision manoeuvreability, navigation and pilotage, and these to no small degree offset the advantages of a considerable reduction in the initial launch weight. For of course it will be apppreciated that in a rendezvous between spaceships, or between a spaceship and a *spacestation*, there would be no sensible gravitational attraction to facilitate homing, as would, on the other hand, be the case in seeking a planet or moon.

Nevertheless, let us go back to the beginning and trace the present trend in rocketry, for I think it will indicate that the stepping-stone method of crossing to the Moon, which entails a precision rendezvous in space, may, in fact, creep upon us without any deliberate intention on our part to foster and evolve this technique as an approach to the Moon.

At present the larger rockets are being used for research into various phenomena and to collect data about the upper atmosphere. The densities, pressure, temperatures, humidities, constituents and winds of the air up to 100 miles and beyond are being investigated, the velocity of sound and the

ionisation at various levels are also subjects which are being studied, and doubtless before very long we shall know practically all there is to know about the ocean of air in which we crawl and swim. Moreover, in the later stages of this phase of research by rocket we can expect that a better insight into the nature of the polar auroras will be obtained.

On the other hand, research has already begun into subjects which do not end with the outer reaches of the atmosphere. For example, the first high altitude measurement of the earth's magnetic field was attempted with instruments included in an "Aerobee" rocket launched from the White Sands Proving Ground (U.S.) on April 13, 1948, a height of 78 miles being attained.

Cosmic-ray research is, of course, another subject which does not end with the atmosphere. Identification of the nature of the cosmic-ray primaries is exceedingly difficult when an atmosphere intervenes, for degradation of the original entities through collisions with the gas molecules is inevitable, so that the fundamental entity is lost. Probably only when it becomes possible to expose detectors openly to the vacuum of space will the true nature of cosmic radiations become certainly known. In addition, the solar radiations can only be observed accurately from space itself.

Recently, a new line of experiment has begun which also requires the ability to carry on research in space. Fruit flies have been sent aloft in a V2 launched from White Sands, New Mexico, in an attempt to gain information about the effect of cosmic radiations on mutation. This foreshadows the not too distant time when man himself will ascend into space in order to undergo tests designed to reveal his physiological reactions to sub-normal g conditions in all strengths down to zero.

In addition to the foregoing, and parallel with these experiments, research will proceed with the transmission of radio back and forth through the upper atmosphere, partly to facilitate telecontrol of rocket flight, partly to build up an entirely satisfactory system of transmitting instrument readings back to ground bases, and partly with a view to a general investigation of the behaviour of microwaves in transit through the various ionised layers of the world's atmosphere.

All this goes to show that the march of rocket missiles towards greater and greater range will be accompanied by research which will be of great value in those spasms of comparative sanity which from time to time interrupt man's normal obsession and preoccupation with war.

It is probable that the general public, especially Londoners, are already perfectly satisfied with the range of rocket missiles, and possibly the claims of military necessity may ultimately be satisfied with rockets of antipodal range. On the other hand, we can expect that the various sciences will continue to demand bigger and better rockets, for although a missile of antipodal range would be aloft quite a while, much more information could be gathered if the rocket and/or its recording instruments could stay up indefinitely. This condition would, of course, be satisfied if the rocket could be established in an orbit about the earth. As an example, if the rocket finishes by having a velocity (v) tangential to the earth's surface equal to $\sqrt{gr^2/s_x}$ —where g is the mean surface gravitation of the earth, r the radius of the earth, and s_x the

rocket's distance from Earth's centre—then the rocket will continue to pursue a circular orbit about the earth indefinitely—and, of course, without using any more fuel. If this condition obtained with a rocket 500 miles above the earth, at the equator, its velocity would be about 4·66 miles/sec. (7·45 km./sec.), the orbital period would be about 100 minutes, and, assuming that the rocket is travelling in the same direction as the world is rotating, it would complete a circuit of the globe in roughly 107 minutes.

Obviously, such an object would afford opportunity for prolonged study of various natural phenomena, such as the solar and cosmic radiations, and could be used to augment our knowledge of the reflection and refraction of microwave radio. Of course, after a time the batteries would run down and the object would no longer be capable of sending back data—but, even so, ground stations could go on bouncing radio off it indefinitely.

However, an object only 500 miles up has the disadvantage that a whole chain of radio stations would have to be erected in order to keep track of its signals—for remember, it will circle the earth in about 107 minutes. As a matter of fact, viewed from any spot on the earth's surface above which the object passes directly overhead, it would be in sight for only 15 minutes. This means that a girdle of at least 7 ground stations, spaced 3,700 miles apart, would be needed if continuous contact with the object's signals is to be maintained.

The way to overcome this difficulty is to have the object circle the earth at a greater distance. It might, in fact, be convenient to have it orbit the earth at a distance of 22,200 miles up, when its period would be 24 hours. If in a circular orbit, the artificial satellite would then have a velocity of about 1·9 miles/sec. (3·09 km./sec.) and would, of course, remain virtually stationary in Earth's sky.

In an article published in the *Wireless World* during October, 1945, Mr. A. C. Clarke showed how a suitably outfitted object orbiting Earth under the conditions just described could be used to receive television beamed to it and in turn diffuse the programme over nearly an entire hemisphere of the world. Indeed, as Mr. A. C. Clarke has pointed out, only 3 such stations situated 120 degrees apart in this particular orbit would be needed to serve the whole globe. Mr. Clarke's calculations prove that the power commitments of the terrestrially based transmitter component and the associated orbiting diffuser unit are well within practical limits, so there is no difficulty on this score. On the other hand, we have to remember that such a scheme cannot be operated until it becomes possible to establish the orbiting component. Moreover, unless of considerable size and *manned*, these units would have to be extremely reliable, for they would be quite expensive affairs, both as regards construction and projection. Again, we must bear in mind that the relaying orbital component will require a source of power to maintain transmission. The possibility of utilising atomic energy can be admitted, and doubtless would be a convenience from many points of view; nevertheless, solar power, which can be obtained gratis, is not to be despised. The equivalent of nearly 1,400 watts per square metre is available from the sun, and this can be collected by a mirror, or system of mirrors, and concentrated to heat a suitable fluid which in turn can be used

in a closed cycle to drive a turbo-generator. It will be appreciated that the solar collector and the aerial array must be kept facing the sun and the earth respectively: however, although this requirement certainly complicates the mechanism of the spacestation, adaption of existing technique should provide satisfactory results.

We will return to these matters later, but from the foregoing it will be seen that we have now acquired a further excuse for high power rocketry. Moreover, of course, besides being capable of diffusing television programmes, there is no reason why a similar scheme should not be employed for commercial short-wave radio, short-wave broadcasting and radar services. Many variants are possible, and even with nothing more elaborate in the orbit than a simple self-aligning reflector of no very great size, the possibilities are enormous. Indeed, all things considered, including the initial expense of projection, it would seem that in the long run orbital radio relay stations of this kind are likely to be financially economic propositions.

Now, up to the present we have been considering comparatively small objects such as could be carried into the required orbit by rockets—quite big rockets, it is true, but still rockets. Shortly we shall be examining the requirements of much more elaborate structures, *manned* spacestations, which, owing to their bulk, unwieldiness and overall weight cannot be projected entire but must be fabricated in space. Therefore—and it is vitally important to appreciate this point—it is evident that *manned* spacestations, whether just specially outfitted spaceships or specially designed structures, cannot be brought into use until such time as it becomes possible to *return a manned spaceship from space*. Upon brief reflection it is apparent that this entails *at least doubling* the overall velocity requirement of an equivalent *unmanned* rocket capable of settlement in any specific orbit; for of course we cannot leave our men in space indefinitely but must provide for their return. Incidentally, this stipulation, though fairly obvious, has, in fact, sometimes been overlooked in the past—hence the present stressing of the point, which indeed deserves further attention.

Let us then digress for a short while from the main theme of this lecture in order to get a preliminary idea of the difficulties involved in transporting the materials needed to build a fully-fledged spacestation or "*artificial satellite.*" If, firstly, we consider a specialized method of completing a round trip to the moon, we shall, in fact, be killing two birds with one stone, for the commitments of both are substantially similar.

Now, although opinions undoubtedly differ, it is probably true to say that the majority of people think of a moonship as a huge vessel which is constructed with fabulous expense, trouble and incantation, and which is miraculously navigated to the satellite and back again amid the wonder and acclamation of *homo sapiens* and the sublime indifference of the rest of nature.

That the vessel will probably shed various parts of its structure during ascent from Earth and subsequently during the voyage is something usually taken for granted in astronautical circles. However, that this is so will probably come as something of a shock to the layman, who may ultimately have serious doubts whether a supplementary ration of green cheese is, after all, worth

being subjected to bombardment by a novel kind of meteor, even though he had received assurance that the risk of being struck is very small indeed.

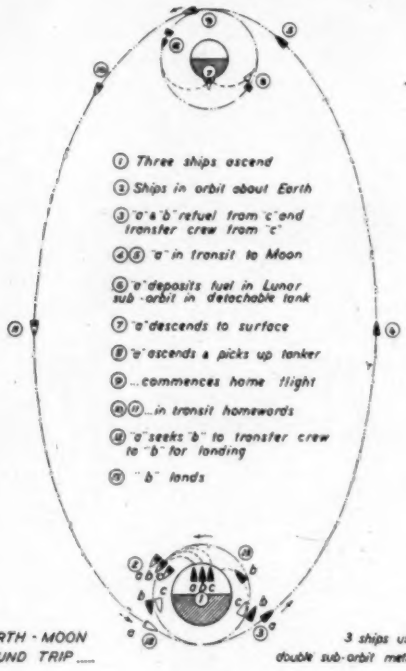
In the scheme about to be described we are, unfortunately, for the present still tied to the idea of jettisoning parts of the ships in order to minimise weight —indeed, we shall be assuming that the vessels employed are compositions of Step and Cellular construction. On the other hand, as just hinted, we shall be invoking more than one ship for the purpose of completing a round trip to the moon. The basis of the particular method about to be outlined has, in fact, been propounded and treated in one form or another by Oberth, Pirquet, "Noordung" and others, but the variant about to be delineated appears to contain some advantages hitherto overlooked. In particular, whereas formerly it was considered that employing more than one ship involved a greater *overall* earth projection weight, this scheme promises to effect a major saving in the total weight launched.

Briefly, the scheme proposes splitting up the Earth-Moon-Earth round trip into stages, on the principle that it is easier for a person to transport a load of bricks a few at a time in this way than it is to attempt to carry the lot all the way in one journey. For the purpose of outlining this scheme it is necessary to make the following assumptions:—

1. That it is possible to build and launch manned cellular-step spaceships of at least 442 tons and preferably not less than 600 tons gross weight.
2. That these ships are capable of developing an exhaust velocity of at least 5 km./sec.
3. That navigation, manoeuvre and pilotage are perfected to a stage where it is possible to obtain precision rendezvousing in space.

The *modus operandi* of the scheme is as follows: three 442-ton ships, each carrying one man, would be launched simultaneously from the earth. They would be navigated and piloted to a rendezvous in a substantially circular orbit 500 miles up. Here they would be warped together and one (A) of the three would be refuelled from the other two (B and C). Ship C would be totally discarded and ship B would be fuelled with the surplus not required by A. With all three men aboard her, ship A, which now weighs about 65·2 tons gross, then departs from the 500-mile sub-orbit, heading for the moon. On approach to the moon, ship A is piloted into a circular orbit, say 500 miles above the satellite. Here fuel tanks weighing about 3·9 tons are detached and left circling in the orbit, whilst ship A descends to the moon. After touchdown on the moon, ship A will weigh about 10 tons gross. In due course ship A rises from the satellite and heads for the 500-mile orbit about Moon. Here, with the aid of radar or other search equipment, it seeks out and comes alongside the fuel tanks which were left in this orbit. This fuel is pumped into the ship, which then heads for the sub-orbit about Earth. Here ship A seeks out ship B and the crew transfer to B. This having been done, ship B decelerates out of the orbit and descends to Earth, terminal braking being perhaps accomplished by means of a constant-drag parachute or parachutes.

At this point it may be remarked that if it should become possible to project unmanned "tankers" into the sub-orbits about Earth and Moon, and to rendezvous these tankers by telecontrol or automatic means, then a single manned ship only might be used, and the whole procedure simplified.


① Three ships ascend
② Ships in orbit about Earth
③ "a" & "b" refuel from "c" and transfer crew from "c"
④⑤ "a" in transit to Moon
⑥ "a" deposits fuel in Lunar sub-orbit in detachable tank
⑦ "a" descends to surface
⑧ "a" ascends & picks up tanker
⑨ ...commences home flight
⑩⑪ ...in transit homewards
⑫ "a" seeks "b" to transfer crew to "b" for landing
⑬ "b" lands
EARTH - MOON ROUND TRIP
3 ships using double sub-orbit method

Round Trip to Moon via Two Sub-Orbits.

DOUBLE SUB-ORBIT EARTH-MOON-EARTH VOYAGE SCHEDULE COMMITMENTS

Exhaust velocity = 5 km./sec. 3 ships about 442 tons each at launch.

	Velocity allowance km./sec.
Ascent to 500 mile orbit about Earth (5 cellular steps).	
7·5 km./sec. plus air-drag, *g*-loss and seeking 2·5 km./sec.	10·0
500 mile Earth sub-orbit transfer to voyage orbit, transfer to sub-orbit Moon (cache fuel tanks in orbit), brake Moon descent (4 cellular steps)	6·5
Ascent from Moon to sub-orbit Moon, seek fuel-tanks left in sub-orbit, transfer to voyage orbit (5 cellular steps)	4·5
Transfer to sub-orbit Earth, seek 34·2-ton ship in Earth sub-orbit (2 cellular steps)	3·0
Brake Earth descent (some air-braking assumed) (3 cellular steps)	8·5
Terminal wt. about 3 tons — Km./sec. total velocity =	32·5

Now, the significance of this scheme may not be immediately apparent—except that 442-tonners, or even 600-ton vessels, are much smaller than we are accustomed to consider feasible for a round trip to the moon. Again, 5 km./sec. exhaust velocity is but half of what would seem to be required as a minimum for a ship designed to go straight to the moon and back without intermediate stages. To illustrate the full measure of the economy in gross projection weight, it must be stated that this scheme is referred to and compares with calculations which Mr. R. A. Smith and I engaged upon in computing the requirements of an "all-in-one-go" moonship. This particular conception involves a story which is too long to embark upon here, but when I say that it engaged our attentions for the best part of two years, it will perhaps be appreciated that the study was comprehensive and detailed. So much so, indeed, that we now shudder every time we think of that task. However, briefly, our conclusions were, that a cellular moonship able to develop 4·6 km./sec. effective exhaust velocity during initial projection and 4·9 km./sec. during the rest of the voyage would have to weigh at least 3,460 tons at launch. On the other hand, the scheme just outlined requires no more than 1,326 tons gross to be projected—and that split up equally between three ships. The saving, then, is considerable. As a matter of fact, a greater margin of safety has been allowed than Mr. Smith and I were able to provide within the commitments of the 3,460-ton ship alluded to.

Nevertheless, 442-ton ships developing 5 km./sec. exhaust velocity must be considered as a daring and barely feasible minimum. Indeed, in practice, it is probable that ships of some 800 tons gross would be needed. On the other hand, if a 10 km./sec. efflux is available, then 442-tonners might suffice. However, naturally all this remains largely pure estimation, for much depends upon the "all-burnt" weight, which, with atomically powered vessels may be considerable, chiefly owing to shielding commitments. Incidentally, "refuelling" might involve physical transfer of full tanks from one ship to another, rather than transfer of the contents alone.

Now, though the foregoing covers a round trip to the moon it also serves to demonstrate the requirements of the ships used to transport the parts of a spacestation into an orbit about Earth. For example, using 442-ton ships it might be possible to get some 30–40 tons of materials to the 24-hour orbit for every 3 ships launched from Earth, and this would include getting our men back again.

It will, of course, be appreciated that ability to rendezvous in space is an essential concomitant of this type of project. However, although the difficulties are indeed formidable, they do not appear insuperable. As a matter of fact, if we manage to survive present world-wide interest in guided missiles, we may, in the end, find ourselves master of a technique which even Homer seems to have envisaged when he wrote:—

> "In wondrous ships, self mov'd, instinct with mind:
> No helm secures their course, no pilot guides:
> Like man intelligent, they plough the tides."*

* Homer (*Odyssey* viii), Pope's translation.

. . . And if anyone objects that there are no tides in space, then I would remind him of gravitation.

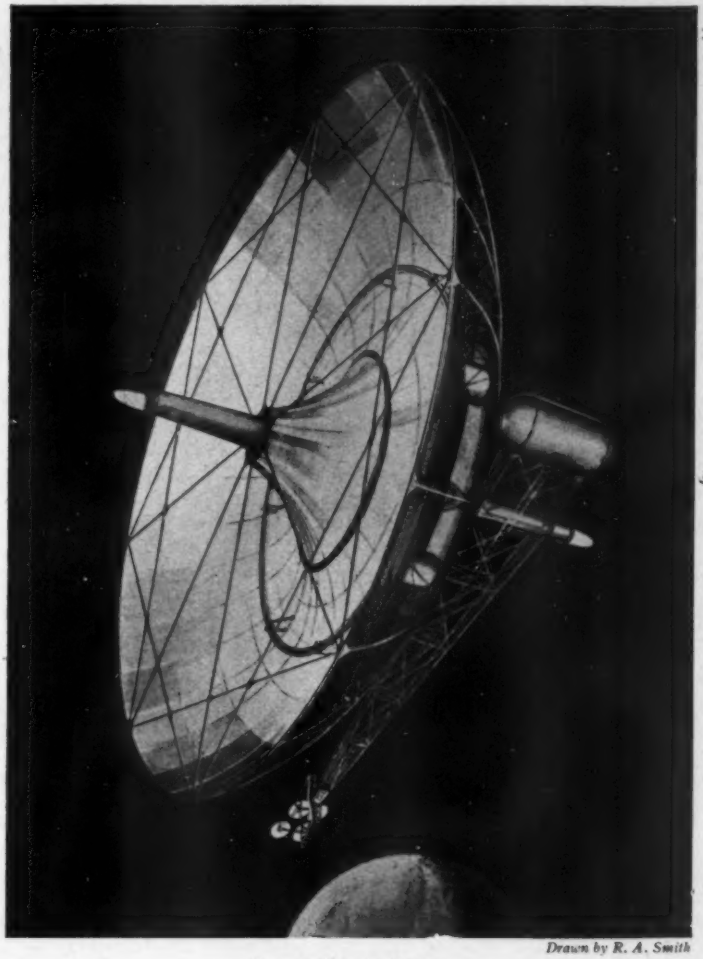
Having demonstrated a method that might be used if we wanted to build a fairly large structure in space, let us now try to visualize what this artificial satellite or *spacestation* might look like. The fundamental requirements were in fact worked out, described and illustrated by "Noordung" many years ago. His conception consisted of three units connected by cables, but the structure formulated by Mr. R. A. Smith and myself is a single self-contained unit. It will be convenient if we make a general survey before delving into the functional detail of the various services.

The station consists of three principal parts: (1) the "bowl"; (2) the "bun"; (3) the "arm." The bowl is a 200-foot diameter mirror; in this version a parabolic annulus, but other forms are possible. This mirror is used to collect and concentrate the sun's rays on to a system of pipes situated at the focus of the mirror. These pipes contain a fluid (let us say water or mercury) and they connect with 8 turbo-generators situated round the circumference of the "bun" behind the bowl. Boiling of the liquid by the trapped solar energy operates the turbines which in turn generate electricity for the station's various services. About 3,900 kilowatts of solar energy is intercepted by this aperture mirror, so that we might reasonably expect that some 1,000 kilowatts would actually become available for use.

The "bun" behind the mirror constitutes the living quarters, laboratories, workshops, etc. Since it is highly probable that entire absence of gravitational datum is undesirable physiologically, and certainly would be a considerable nuisance when moving about, it is necessary to rotate the inhabited part of the station. The bun living quarters being in this case conveniently integral with the solar mirror, the whole of this part of the structure is made to rotate in order to provide a pseudo-gravitational effect. Since the living quarters are in this design arranged as two concentric galleries, in effect a two-storeyed building, the g will differ in the two levels. However, with the bowl (and bun) rotating once in 7 seconds, the g three feet from the floor of the two galleries will be 1 g in the outer and 0·43 g in the inner—which is probably a satisfactory compromise. In any case, manifestly it would be a simple matter to arrange for single-storey accommodation at the expense of compactness.

Control of the "attitude" of the station as a whole, which if nothing else must at least rotate about a diameter once per year, in order to keep the bowl facing the sun, is achieved by the "box" of 6 electrically powered gyros situated at the hub of the station. A photo-electric servo link between the mirror and these gyros could make the station automatically self-compensating in this respect.

The arm behind the bowl mirror normally does not rotate. At one end of this arm is a chamber with two air-locks. This chamber serves the dual purpose of a no-gravity laboratory and means of entrance to and exit from the spacestation. The far end of the arm carries the radio aerial array which provide communication with Earth and can also be used for diffusing television or other radio services beamed to the station. The radio array would normally be gyro-stabilised to hold a constant direction in space irrespective of any



Drawn by R. A. Smith

Spacestation in Space

change of attitude of the station. Furthermore, automatic control would be incorporated to lock the Earth-Station-Earth beams. In addition, an over-riding manual control would allow re-orientation of the various units of the arrays independently and at will. This, among other uses, would permit communication with and navigational assistance of a spaceship in transit between the earth and the station, and vice versa.

It is not necessary to describe in detail all the points of the layout, most

of which will be apparent upon inspection of the internal schematic, but the *strobotelescopes* are worth some explanation.

Briefly, these are based on the principle of the *Coelostat* developed and demonstrated in 1939 by the Technical Committee of the B.I.S. As then visualised, the function of the coelostat, which is a simple but ingenious optical system consisting of two fixed and two rotating mirrors, was to present to the eye of an observer a stationary image of a rotating scene. Manifestly some device of this nature is needed if anything outside the station is to be looked at, for the station is, of course, rotating. A stationary image of a rotating scene can, of course, be obtained by employing adapted television apparatus. However, such a system labours under the disadvantage of insufficient sensitivity to starlight and insufficient fineness in the iconoscope mosaic and grain of the viewing tube. In short, stellar observation is not at present possible with such a system. On the other hand, the coelostat device does not suffer these disabilities—and, moreover, is infinitely simpler. The *strobotelescope*, developed by Mr. Smith and myself, consists of a telescope with a built-in coelostat and an exterior plane mirror, or system of mirrors—which latter accessory enables the instrument to be sighted in practically any direction of a celestial hemisphere without the whole strobotelescope being turned bodily.

As will be seen from the drawings, two such instruments are incorporated at the axis of the station, the barrel of one serving as the bearing for the lattice arm. It should be understood that the exterior mirrors would be capable of being rotated equatorially and adjusted in polar angle at will, in order to sight in the required direction, and that the mirror head entire would be fitted with a self-compensating mechanism that, normally, would keep the head pointing in the required direction. In essence, the latter requirement simply means that the mirror head would be synchronously driven counter to the revolving barrel of the strobotelescope on which it is mounted.

In operation, what actually happens is that the light impinging on the exterior mirror system is reflected down the barrel of a normal telescope (which may be either a reflector or refractor, as convenient) and then passes through the coelostat unit and eyepiece to the eye of the observer—or, alternatively, to a photographic plate. Since two strobotelescopes are provided, and since each can be sighted at will virtually in any direction of a celestial hemisphere, practically any part of the whole star-sphere can be studied at any time without changing the attitude of the station.

The functions which this particular station could perform are fairly self-evident upon inspection of the internal layout drawing, but a few remarks may be enlightening. To begin with, the strobotelescopes (which might have apertures of the order of 40 to 60 in.) could be used for meteorological study of the earth. Indeed, a great deal might be learned about the brewing of Earth's weather by the especially comprehensive, if long-range, inspection which this artificial satellite can afford. Again, since the strobotelescopes would be operating under practically ideal conditions—not peering through a quivering and slightly opaque atmosphere but situated in airless space—very high magnification indeed could be used at all times and true spectra of the sun and stars would be obtained. This is, of course, not possible when an atmosphere

intervenes, a fact which especially clouds with uncertainty the determination of the constituents of the atmospheres of the other planets of our solar system. Against this we should bear in mind that in order to obtain a stationary image and sight in various directions without re-orienting the barrel of the strobotelescope, it has been necessary to introduce several more reflections than is normal to astronomical telescopy, so that some sacrifice in image brightness, etc., is unavoidable. Moreover, the mirror head mechanism and the coelostat must both be precision jobs. However, for special occasions the bowl should be brought to a standstill, the station oriented to sight a strobotelescope direct upon the object, the exterior mirror system swung clear of the line of sight, the coelostat removed, and an ordinary telescopic view or photograph obtained.

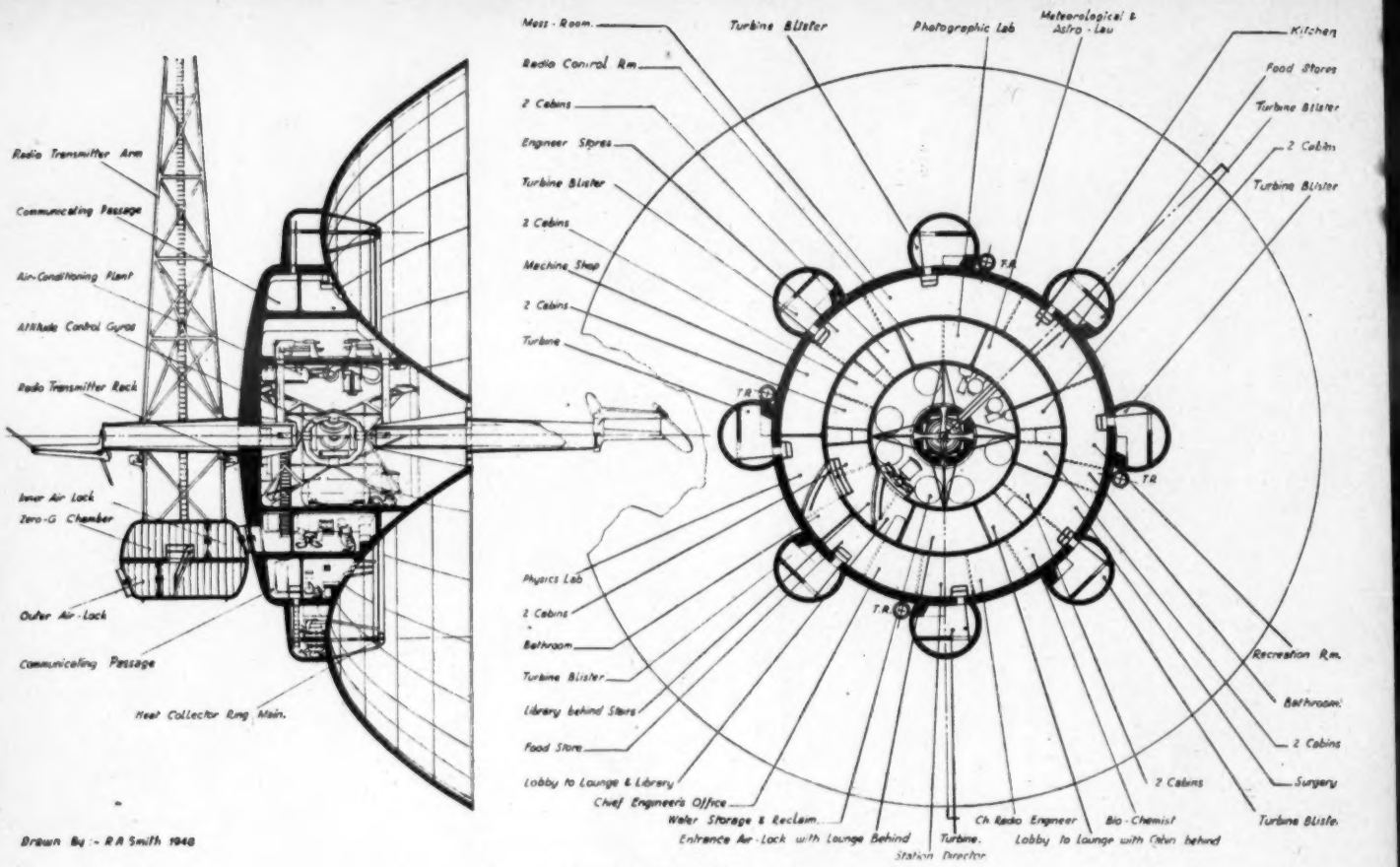
The function of the Photographic Laboratory is obviously that of providing a recording service for the other laboratories. Of course the Physics Laboratory would, among other things, investigate cosmic-ray and solar radiation phenomena, and it will be noticed that a biochemist has been co-opted to conduct research into the effect of various radiations upon living organisms. In addition, the scientist would have the unique advantage over his terrestrially-located colleagues in that he can use the no-gravity chamber for a whole new range of experiments.

Besides the foregoing, we can envisage that apart from any ordinary radio relay services which the station's adequate gear might provide, there would be opportunity to conduct a number of highly interesting experiments in connection with the reflection and refraction of various radio frequencies by the earth's atmosphere.

Upon further consideration, a number of other uses for such a station as this will become apparent—for example, that with vacuum "on tap" it is an admirable site for "atom-smashing" machines like cyclotrons and betatrons which not infrequently fail under terrestrial conditions through developing a leak in the evacuated chamber. Several more possible uses and variants of spacestation technique will be given at an appropriate time later in this talk.

As a point of interest, it may be mentioned that the two galleries which together comprise the living quarters and work-rooms of the station, if "unwound" and laid out flat would be equal to a single storeyed building no less than 450 feet long by about 16 feet wide by 10 feet high. The domestic accommodation alone, apart from the laboratories, etc., include a mess room, kitchen, recreation room, surgery, library, personal cabins and two bathrooms, and this should be entirely adequate for the staff of 24 which we have in mind. This may seem to be an unnecessarily large number, but is in fact not excessive when it is realised that a 24-hour radio service is being catered for and that a good deal of highly exacting maintenance will probably be needed. The staff suggested is as follows:—

1 Station Director.
1 Deputy Station Director.
1 Chief Mechanical Engineer
3 Assistant Mechanical Engineers.
1 Chief Electrical Engineer.
3 Assistant Electrical Engineers.
2 Astronomers.
2 Meteorologists.
2 Physicists.
2 Biochemists (one an M.D.).
2 Cooks.
4 Orderlies.



Diagramatic View of Spacestation

Before passing to other matters, let us pause to describe the procedure that would obtain when (let us say) it becomes necessary to take on stores. For of course such things as air, water and food must be replenished, however good the reclamation service which are installed as part of the station's vital equipment. Besides which, in any case, a change of personnel will have to take place from time to time.

Briefly, the procedure of exchanging personnel, taking on stores, etc., would be as follows:—

1. The lattice arm (which is stationary) is made to rotate in unison with the bowl—this being done by the gradual application of a clutch mechanism between the arm and the barrel of the strobotelescope. When finally locked together, the no-gravity chamber is opposite the outer air-lock hatch in the living quarters.
2. The members of the crew due to leave the spacestation now don spacesuits and pass through the air-lock into the no-gravity chamber.
3. The lattice arm is now declutched and counter-driven until stationary, the no-gravity chamber being in such an attitude as to give it a clear line of sight of the nearby spaceship.
4. The men in the no-gravity chamber now reduce the chamber to vacuum and open the far air-lock hatch.
5. A cable is then passed across from the spaceship to the no-gravity chamber, or vice versa—let us say, carried over by a small guidable rocket.
6. A link has now been established between ship and station along which stores and personnel can pass. A kind of breeches-buoy method of transportation may be assumed.
7. Stores and/or personnel having been transferred, the cable link is broken and the spaceship is free to depart.
8. The far air-lock hatch of the no-gravity chamber is now closed and the lattice arm is once again locked to the bowl and brought stationary with respect to it, with the near-side air-lock hatch opposite the hatch in the living quarters.
9. The stores are now shifted from the no-gravity chamber into the air-lock in the living quarters and the air-lock hatch is closed.
10. The lattice arm is then declutched and counter-driven until stationary.
11. The living quarters' air-lock is now flooded with air, the inner hatch opened, and the newly arrived stores can be transferred at leisure to their appropriate locations in the station.

It will be observed that the process of transferring between spaceship and spacestation, or vice versa, can be performed *with the bowl rotating*. In other words, the normal g of the station remains unaltered throughout—which obviously is a material advantage well worth the somewhat complicated operations involved.

The question of replacement of stores having been raised, it now behoves us to consider these items in some detail.

Up to the present very little serious attention seems to have been paid by anyone to this absolutely vital concomitant of space travel—though it is true that an article on the subject by Maurice K. Hanson appeared in the *B.I.S. Journal* of January, 1939.

Let us then attempt a brief summary of the essential items under the three headings, Food, Air, Water, including in the review some idea of how it may be possible to cope with air and temperature conditioning and various reclamation problems.

Food.—As regards quantity, we are probably absolutely limited only by costliness of transport to the station. Nevertheless, there is, of course, a minimum ration which must be maintained. However, as regards weight, there is no special point in supplying rigorously dehydrated or "tabloid" foods because neither bulk nor water can be cut indefinitely. The present-day normal ration of food for a polar explorer is 2 lbs. per day; so if we say that we will put the allotment at 3 lbs. of food per man per day we shall have made a reasonable allowance. On this basis the spacestation staff of 24 men will consume 72 lbs. of food per day. A little simple arithmetic tells us that if a supply ship visits the station once every three months, it should bring at least 2·97 tons of food. The gross weight of food consumed in one year is, therefore, about 11·88 tons, if 24 men are being fed—on top of which there is of course the weight of the containers to be taken into account.

As regards the gross proportions of protein, fat, carbohydrate and mineral content of the foods supplied, it is probably best to assume that the standard requirements should be satisfied. Care should of course be taken that the food ration is capable of furnishing the required number of calories, the normal being 3,000 kilocalories per man/day. In view of the small amount of manual work required of the staff, and the uniformity of the station's air temperature, it is, however, possible that a yield of 2,000 kilocalories would suffice. In addition, the vitamin content of the foods supplied should be studied. All in all, a very carefully balanced and proportioned diet, formulated to meet the special circumstances of spacestation life, is required. However, fortunately, there is no reason why the foods should not be varied and appetising to a degree which we in Britain to-day might well envy—especially if the Station Director exercises his authority to the point of insisting upon the services of a French chef. In which case, doubtless there will also be some very good wines on the menu.

Air and Water.—The requirements here can conveniently be considered together—for it will be assumed that the air and water are being obtained from hydrogen peroxide, since, all things considered, the storage of liquid oxygen over long periods introduces several new difficulties. Moreover, this talk is strictly limited in space and time co-ordinates, so that it is impossible to argue out all the pros and cons of various systems.

Indeed, all that can be done is to hint that the problems associated with air-supply and air-conditioning are very much more abstruse, ramified and

exasperating than is generally realised. Perhaps for this very reason these matters are seldom probed to any appreciable depth either in fiction or the otherwise fairly comprehensive works of the astronautical *illuminati*. However, a measure of the difficulties is readily obtained by considering submarines, which, even today, are forced to rely principally upon natural air for their atmospheres.

The proposal to utilise hydrogen perioxide as the common source of oxygen and water appears to originate with the pre-war Technical Committee of the B.I.S., being in fact set out in the article by Hanson previously referred to. However, at that time hydrogen peroxide of sufficient concentration was difficult to obtain except in small quantities, and as a "laboratory" product. One cannot help commenting that here again is a case where, as the celebrated writer John Russell might say, *"prophets have cried out in print, no man regarding."**

In order to assess the air and water requirements, it is first of all necessary to settle the "work-level"—that is, degree of physical exertion—which might be expected to correspond with the activities of the staff of the spacestation. For, of course, the degree of physical exertion governs the amount of air and water required. In this connection, it would appear that we might reasonably assume that the degree of physical exertion which obtains in the case of a man walking on grass at 2 m.p.h. is a satisfactory basis. Indeed, since for something like 8 out of every 24 hours each of the men would be asleep or resting, the adoption of the 2 m.p.h. work-level for the full 24 hours should give ample cover. Having arrived at this decision, the basic oxygen and water requirements can be calculated from the generally accepted 2 m.p.h. work-level commitment. The requirements are as follows:—

Oxygen and Water Requirements for 24 *Men per* 24 *Hours.*

Oxygen: 26,952 litres = 38·5 kgrms. = 84·7 lbs.

Water—variable, but about: 180 pints = 102·15 kgrms. = 225 lbs.

However, as regards water, we have to bear in mind that additional demands arise in respect of such things as cooking and washing (personal and clothes). When this is taken into consideration we may feel inclined to allot 9 pints (11·25 lbs.) of water per man/day for beverages, cooking and general needs plus 30 gallons (300 lbs.) per man/week as cover for bathing and washing generally. This, then, brings up the water requirement from the "academic" level to the practical level of:—

Total water required per day by staff of 24 = 1,302 lbs.

However, it is not necessary to supply water to the station at this rate, for considerable reclamation can be operated. Indeed, it would seem feasible to assume that all bar 270 lbs. of water out of the daily "consumption" of 1,302 lbs. could be reclaimed.

There are several ways of doing this, but in the long run probably a distillation method would prove most economical.

* *The Lost God* (South Seas Islands Omnibus), Eyre & Spottiswode, London.

Doubtless some additional treatment would be required: however, this is the significant process.

Subtracting 270 lbs. of water considered unreclaimable from the 1,302 lbs. daily water consumption, we can proceed to calculate the power required to distil 1,032 lbs. of water in 24 hours. Having done this, we find that the theoretical requirement demands the continuous expenditure of some 14 kilowatts. Recalling the figure of 1,000 kilowatts at 25 per cent. efficiency given earlier for the mirror, manifestly ample power remains for other services.

We now know the water requirement but have yet to determine the quantity of hydrogen peroxide that would be needed to meet our commitments. Taking it that an overall wastage of oxygen amounting to 4 per cent. will occur through leakage, we can proceed to calculate the weight of hydrogen peroxide needed to contain 88·2 lbs. (40 kgrms.) of oxygen, this figure being the revised consumption rate per day for 24 men.

Assuming that the hydrogen peroxide will be a 90 per cent. concentrate, and allowing for stabilisers, we discover that 210 lbs. of hydrogen peroxide is required per day, and that 121 lbs. of this will be water.

This provides us with the following conclusions:—

	lbs. per day	Tons per 3 months	Tons per year
Hydrogen peroxide	210·0	8·64	34·56
Extra water separately	149·0	6·12	24·48
Food	72·0	2·97	11·88
	431·0	17·73	70·92

Incidentally, it should be appreciated that it is a distinct advantage to have some pure water supplied separately, rather than weaker hydrogen peroxide—for if *all* the water is locked up in H_2O_2, free water for drinking, etc., will not be available until some of the hydrogen peroxide has been dissociated. In which case, at best, this would obviously entail treatment of small batches of hydrogen peroxide, not catalysis of the whole stock.

It is not possible at the present time to state with any certainty the best kind of atmosphere for the station—that is, whether it is best to use pure oxygen at the reduced pressure of, say, about 160 mm. of mercury, or a specially proportioned mixture of oxygen and nitrogen, or again, a specially constituted mixture of oxygen and another inert gas, such as helium. Or again, just ordinary air at normal or somewhat reduced pressure. However, it may be said that one of the prime aims should be to keep the atmospheric pressure as low as physiological and biological reactions permit, for by doing so loss by leakage will be minimised. Therefore, if by actual experiment it is found that pure oxygen at reduced pressure can be breathed over exceptionally long periods without harmful results, then pure oxygen is preferable. It should, however, be appreciated that the nitrogen content of a natural atmospheric air is seemingly only a diluent, so that in the case of an oxygen plus diluent atmosphere, *only the oxygen has to be replaced*, except, of course, a small quantity

of the inert constituent to make good leakage loss. At this juncture it is necessary to remark that a very small carbon dioxide content in breathed air is desirable, if not absolutely essential, for in small quantity this gas acts as a respiratory stimulant.

It should, of course, not be forgotten that the atmosphere of the station must be kept pure, the principle contamination arising from the carbon dioxide of respiration. With 24 men aboard, and assuming the 2 m.p.h. work-level as the average of physical exertion, we know by experiment that the carbon dioxide fouling-rate will be about 15·9 litres (33·4 grams) per minute. The problem that faces us is, therefore, the elimination of some 22,900 litres or 48·0 kilograms (106 lbs.) of carbon dioxide from the atmosphere of the station every 24 hours.

Now, elimination of carbon dioxide from an atmosphere can, of course, be achieved in various ways—for example, by chemical absorption or adsorption, by centrifuging, fractional liquefaction, etc., etc. However, simplicity is a major attraction under the circumstances which face us in the case of space-station. Since the back of the station will always face away from the sun, conditions of extreme cold, approaching close to zero temperature can be obtained without much difficulty. As Oberth has pointed out, it would indeed be possible to conduct the fouled air of the station through pipes exposed on the dark side and literally precipitate the carbon dioxide by freezing. Some complications naturally ensue in practice owing to accumulation of carbon dioxide in the ducts, but clearance by reheat and release of the gas to space could be arranged without much difficulty. (This system is, however, more troublesome to reduce to practice in the case of a *rotating spaceship*.)

One or two further points in connection with the elimination of carbon dioxide may be mentioned briefly. By the use of certain chemicals, such as sodium perioxide, which in contact with carbon dioxide *evolve oxygen*, or gain by thermal cracking of carbon dioxide, it would be possible to realise a considerable economy in the oxygen supply rate. In no case a 100 per cent. saving, however, for some oxygen is inevitably "lost" to the body. Nevertheless, the required chemical processes are messy, and except where regeneration of a CO_2 adsorbent or absorbent is easily possible, enormous quantities of material would be required for the station we are considering. Indeed, the cost of transporting the chemicals to the station initially, together with, in most cases, replacement at frequent intervals, is generally prohibitive, especially for so large a staff as 24. Thermal cracking and other means demanding considerable power are worthy of consideration if practical and within the capacity of the solar mirror, but the subject is too long to enter upon here. As for regeneration of the atmosphere of the station by green vegetation—well, apart from the fact that a supply of oxygen would still be needed, this method is open to severe practical criticism—especially so if operation over long periods of time is required.

The question of the removal of the water vapour exhaled by the crew can now be considered. As a matter of fact, some 62 kgrms. (137 lbs.) of water would be discharged every 24 hours from the lungs and skin of the 24 occupants of the station.

Manifestly, if it is possible to secure a temperature low enough to permit the precipitation of carbon dioxide from the air of the station, it will be possible to freeze out the water vapour content. It would, therefore, seem feasible to assume that the air of the station would be circulated first through a section of ducting kept just below the dew point, where the water vapour content would condense out, and then through a section of piping at considerably lower temperature, where the CO_2 would be precipitated. After this, possibly a water-wash, followed by drying and temperature conditioning would be needed before the regenerated air is finally returned to the living quarters.

As regards general thermal insulation and the avoidance of excessive loss of heat by radiation, which is, of course, part and parcel of the temperature conditioning problem, it would seem that the exterior walls of the station must be double, with vacuum between, and all surfaces should have a bright finish. This arrangement will provide highly effective thermal insulation, such as is essential in order to minimize the rate of gain or loss of calories from various parts of the living quarters. Though Mr. Smith and I have not calculated the thermal balance of solar increment plus crew body-heat plus the heat generated by services and equipment against loss due to radiation, we judge from previous computations of somewhat similar structures, that the thermal insulation of the station could be adjusted without much difficulty to require either a little extra heating by utilization of power from the solar mirror or a little cooling by refrigeration piping. On the whole, it would seem preferable to aim to require cooling rather than heating, for the latter will absorb some of the power provided by the solar mirror which might otherwise be more usefully engaged.

We have now covered most of the prime services of the spacestation we have been considering, and although obviously there there are many more points which might be discussed, it is time to draw to an end. Indeed, I must leave to your own imaginations the peculiarities of living aboard one of these artificial satellites, with its upcurved floors that give the impresson that one's colleagues are about to fall down, and its concave billiards table that looks impossible but on which the balls roll quite normally.

It now only remains to say, that once it becomes possible to build spaceships capable of achieving orbital velocity, a number of other schemes fall into line for consideration. For example, an enormous saving in electrical power would be effected if we could rely upon having a full moon every night—or, better still, the equivalent of several full moons simultaneously. Who knows? —perhaps at some time in the future we may indeed have several swarms of objects like silvered table-tennis balls moving in an orbit round the earth and providing additional illumination at night; though, of course, such a swarm would have to be very big indeed, certainly not less than 10 miles across, and perhaps even 240 miles or more in diameter, depending on distance, to equal the brilliance of full moon. Or again, raising the size of the units somewhat, one might employ structures rather like chinese lanterns—a paper affair, silvered on the outside and puffed up just after ejection from the "moonlaying" spaceship. Units of this kind might, perhaps, be about 50 feet across when distended, and, being light and easily stowable when folded, a spaceship could carry a large number at one trip. Yet another possibility is contained in the

ejection of small grains, dust, or smoke, from flocks of rockets which have been directed into an orbit about the earth. In the ultimate, this envisages the establishment of one or more rings encircling the world, similar to, but less extensive than, those of the planet Saturn. Incidentally, fantastic though such schemes may seem by reason of the magnitude of the undertakings, it is well to bear in mind that projects such as these do not require *manned spaceships* but could be carried out with relatively small and comparatively simple tele-controlled or entirely robot *rockets*.

REFERENCES

Bonham, L. D., "Air-conditioning the Stratosphere Gondola," (Explorer II), *National Geographic Mag.*, 1936.
Davis, R. H., *Breathing in Irrespirable Atmospheres*, St. Catherine Press, Ltd., London.
"Noordung," H., *Das Problem der Befahrung des Weltraums*, Berlin, 1928.
Ross, H. E., "Air-conditioning Problems of Rocket Travel," *B.I.S. Bulletin*, No. 1, Vol. 1, November, 1946.; "Green Plants as Atmosphere Regenerators," *B.I.S. Bulletin*, No. 1, Vol. 2, January, 1947.
Starling, E. H., *Principles of Human Physiology*, J. & A. Churchill, London.

NOTES AND NEWS

Third Annual General Meeting

The business at the Third Annual General Meeting held on December 17, 1948, was transacted speedily. After the adoption of the Society's accounts for the year to September 30, 1948, the meeting then went on to elect a new Council of the Society, to hold office during the session, 1948–9, and to re-elect Mr. T. W. Woods as auditor.

In introducing the retiring Council's proposals for the amendment of the Society's Articles of Association, Mr. Cleaver explained that our constitution had been drafted by Mr. L. J. Carter largely with a view to giving effect to the pre-war organization of the B.I.S. The Council had always recognized that some changes might later be seen to be desirable, in view of practical working experience, and they now felt that the changes to be considered would be of value and assistance in the conduct of the Society's affairs.

The meeting then proceeded to consider these proposals, and the Chairman formally proposed the adoption of the motion from the Chair. This was seconded by Mr. W. N. Neat, and carried unanimously.

The meeting then went on to discuss a number of interesting topics relating to the Society's affairs and the position of astronautics generally at the present time, to which the Chairman and Secretary replied as occasion arose.

Conversazione and Model Construction

The Council has been considering an interesting suggestion that a Conversazione be held as an opening feature for the lecture session, 1949–50, and with this in view, they would be greatly interested to hear from any members who have any photographs of models which could be used.

As a matter of some historical record, the Council is also exploring the suggestion that a model of the pre-war B.I.S. spaceship be constructed, and they would be pleased to know of any members who would like to assist in this

type of work. In addition to this particular model, a number of other suggestions have been made, but it will necessarily depend on the facilities available as to which of these might be later adopted.

Any members interested should write to the Technical Director, Mr. L. R. Shepherd, at 28 Avon Road, Chilton, Bucks, to inform him if they could supply practical assistance or if they have any interesting exhibits.

French Astronautical Developments

We have recently received an interesting letter from M. Ananoff giving details of the development of astronautics in France during recent years, and advising us of the formation of the *Groupement Astronautique Français*, the third group which has been founded in the ten years between 1938 and 1948.

The first had been associated with the *Société Astronomique de France* as their "Astronautics Section," the initial formation being undertaken by M. Ananoff and M. André Hirsch to aid the recruitment of contenders for the Rep-Hirsch Prize. There were many difficulties, but membership rose to 150 before the war interrupted activities.

On the return of M. Ananoff from captivity (where he had managed to hold several meetings on astronautics in his prison camp!), a second movement was founded within *L'aero-club Universitaire et Scolaire de France* (Aero Club of French Universities and Schools), but after two years of activity, which saw a number of issues of their publication *L'Astronef*, the movement came to a standstill through lack of funds.

Shortly following the dissolution of this group, the third and present group was founded within *L'Aeronautique-Club de France* and is known as the *Groupement Astronautique Français*.

We extend our best wishes to our French colleagues and have every hope that their perseverence will, in good time, bring its own due reward.

A Russian View of Astronautics

We are indebted to the American Magazine, *Time* (for July 12, 1948) for the following information. It appears that the Soviet youth periodical *Ogonek* asked a number of young citizens of the U.S.S.R. to set down their hopes, ideals and ambitions for the future, at the time in their lives when they were just about to start their university education. Among the selection reprinted in *Time*, there occurs this one:—

> ". . . But blond, slant-eyed Vladimir Barkov has no doubts whatever concerning the year 1963. By then, believes Vladimir, triumphant Soviet science will have perfected atomic control and powered a voyage to the moon."

Out of thousands of applicants, three young men will be chosen to man the first Mars-bound ship. Vladimir will be one. "Before starting," he writes, "I peruse my diaries and see how happy were my years of study and research which led to this interplanetary trip. In our collective efforts I never felt the loneliness experienced by scientists in capitalist countries.'".

Evolution of Energy in Jet and Rocket Propulsion

We understand from the Editor of *Aircraft Engineering* that the series of six articles under the above title by Mr. Bielkowicz has proved so popular that all these issues are now out of print. However, a few blue-print copies of the articles are still available at the nominal price of five shillings.

Extra Copies of Journals to Members

In future it is hoped to make available to members extra copies of *Journals* at a much reduced price, subject only to stocks being available. At present the following are in hand and copies can be obtained from the Secretary at 1s. 6d. each, post free.

1947 Annual Report and List of Members.
1947 *Journal*, Vol. 6, No. 7 (Dec.).
1948 ,, Vol. 7, No. 3 (May), No. 4 (July), and No. 5 (September).

Nickel Alloy Steels

The Mond Nickel Company has recently issued an up-to-date summary of the properties and more important uses of nickel alloy steels, which forms a useful guide to the solution of many engineering problems. Copies of this booklet may be obtained free of charge by members on application to The Mond Nickel Co., Ltd., Grosvenor House, Park Lane, London, W.1.

Acknowledgments.

The Council desires to acknowledge with many thanks the following donations:—

L'Astronautique and *Complement* (Pelterie) from R. Lencement.
Flights into the Future (Harper) and *Physics of Rockets* from A. V. Cleaver.
Propulsori a Reazione per L'Astronautica (L. Gussalli) from the Author.

WANTED.—Copy of *Rockets through Space* (Cleator). N. M. Brown, 320, Hill Street, Lansing 12, Michigan, U.S.A.

FOR SALE.—3 in. equatorial telescope, finder, sun and star spectroscope, 3 astro. and 1 day eyepiece. Garden stand. £30. F. E. Day, 94 Hillview Gardens, N.W.4.

KNOW YOUR COUNCIL

ARTHUR CHARLES CLARKE, B.Sc. Born 1917. Educated at Huish's Grammar School, Taunton. Was an executive officer in H.M. Exchequer and Audit Department, 1936–41, when he entered the Royal Air Force as a radar mechanic. Until 1943 he was a lecturer in radar theory at No. 9 Radio School, Yatesbury, where, for some unaccountable reason he acquired the sobriquet "Rockets." After commissioning in 1943 he joined Professor Luis Alvarez' Radiation Laboratory team, which was then carrying out development tests on the first G.C.A. (Ground Controlled Approach) microwave blind landing unit.

When the American scientists left—Professor Alvarez, as it later turned out, to make an appointment with History on August 6, 1945, on a small Pacific island—Mr. Clarke became the G.C.A. unit's technical officer and was responsible for the training of R.A.F. maintenance staff. He remained on G.C.A., being chiefly concerned with synthetic training equipment and airfield installations, until demobilized in 1946 with the rank of Flight-Lieutenant.

Having resigned from the civil service, Mr. Clarke entered King's College, University of London, and obtained a First Class Honours Degree in Physics and Mathematics in 1948. He is now taking a post-graduate course in dynamics and astronomy.

Mr. Clarke joined the B.I.S. in 1935 and was its pre-war treasurer and editor of the "Bulletin." He initiated the discussions which, at the close of the war, resulted in the amalgamation of the existing astronautical societies in this country. In 1947 he was Chairman of the B.I.S. and is now Assistant Secretary and one of the three members of the Publications Committee. He is also a member of the British Astronomical Association and has done a good deal of observing with a 3-in. refractor.

Since 1944 Mr. Clarke has published some 20 articles on various aspects of electronics, rocketry and astronautics, including the essay "The Challenge of the Spaceship," several radio scripts, and the entry "Astronautics" in the new "Chambers' Encyclopaedia." He has also published 15 stories, most of which—including a short novel, *Against the Fall of Night*—have appeared in the United States.

E. BURGESS. Born 1920, educated at the High School of Commerce, Manchester. Worked pre-war as assistant accountant to firm of motor engineers and distributors, now accountant and secretary to a group of Manchester textile companies. Served with the R.A.F. for five and a half years, acting as a technical instructor: also during this period he also organized meetings in various parts of the country for the C.B.A.S., discussing rocketry and interplanetary flight.

Originally interested in astronomy, Mr. Burgess formed an interplanetary society in Manchester in 1936, meeting M. R. Esnault-Pelterie in Paris the following year and established a rocket proving ground on the Pennines for the Society. He was elected President and held that office until the Society became the Northern Group of the C.B.A.S., when he was elected to the Presidency of that Society.

He was a member of the group which, during the war, studied the formation and constitution of a proposed national post-war society, to revive the B.I.S. and amalgamate with the C.B.A.S. and helped to form that which we all now know as the new B.I.S. He acted as Chairman of the Council of the B.I.S. for the first post-war session, 1945-46.

Lectured on interplanetary flight to provincial astronomical societies from 1937 onwards, and at present is a keen photographer of the Moon, an honorary warden of the Godlee Observatory, College of Technology, Manchester, and on the Council of the Manchester Astronomical Society. A writer and lecturer on rockets and interplanetary flight and regularly contributes to well-known aeronautical and engineering periodicals. In 1946, Mr. Burgess, together with another Council member, Mr. Clarke, scooped for the B.I.S., second and first prizes respectively in an essay competition, *Effects of Guided Missiles on Future Warfare*, organized by the Royal Air Force Quarterly for all members of the Royal and Dominion Air Forces.

THE ATOMIC ROCKET—3*

By L. R. Shepherd, B.Sc., A.Inst.P., and A. V. Cleaver, A.R.Ae.S.

5.—The Reactor

In the preceding sections, it was shown that the very high exhaust velocities necessary for true interplanetary flight could be obtained if suitable propellant fluids could be heated by nuclear reactions to temperatures in the range 3,000–5,000° K. and then allowed to expand through a propulsive nozzle. It was shown, furthermore, that the amount of energy released in a nuclear reaction is sufficient for the propellant mass ejected to be some 10^5 to 10^6 times as great as that of the nuclear fuel which need be consumed. It remains to consider the prospects of achieving the necessary energy transfer, from "fuel" to "propellant," in the nuclear reactor itself.

The conditions under which this operation would have to take place may be summarized roughly as follows:—

(i) The propellant must reach a final temperature in the region 3,000–5,000° K.

(ii) The chamber pressure must be limited to about 100 atmospheres—as a conceivable maximum, in the absence of any structural materials or techniques far surpassing any known today.

(iii) The energy transfer must be at the rate of about 10^5 kilowatts/tonne thrust, for an overall thermal efficiency of 50 per cent., or twice that figure if the efficiency is only 25 per cent.

(iv) The propellant mass flow through the reactor must be at the rate of about 1 kg./sec./tonne thrust, for a specific impulse of 1,000 secs. (i.e. $v_e \simeq 10$ km./sec.).

(v) The propulsion unit must be capable of functioning continuously at full power for periods up to 20 minutes (e.g. assuming acceleration to escape velocity at 1g effective).

In considering the above figures, it should be remembered that the thrust requirement for a spaceship is likely to be of the order of several hundred tonnes.

The two possible types of fission chain reactor which will be considered in this paper are indicated very diagrammatically in Figs. 3 and 4; they are:

(*a*) The Solid Reactor; and

(*b*) The Gaseous Reactor.

Clearly, some combination of the two systems is a third possibility but critical conditions and physical characteristics can best be discussed from a study of each separately. Type (*a*) would be an extension of the kind of reactor already under development for industrial nuclear power plants, in which a working fluid is blown through suitable channels in a chain reactor, the heat transfer taking place mainly by the conventional means of radiation, convection

* Parts I and II appeared in the September and November, 1948, issues of the *Journal*. The paper was prepared during the winter, 1947-1948, when Mr. L. R. Shepherd was engaged in research studies in nuclear physics at the Cavendish Laboratory.

and conduction (see Fig. 3). Such a method has been proposed in a number of earlier papers; its apparent similarity to a device already approaching realization should not mislead anyone into believing that it represents in any sense an easy problem, since the operating conditions for a rocket application would be vastly more arduous than for the stationary case.

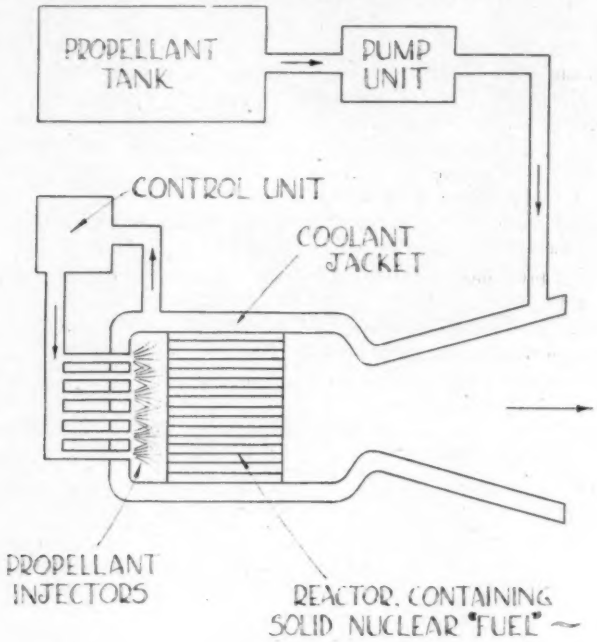


FIG. 3.
Schematic Diagram of Motor using possible "Solid" Reactor.

Type (*b*) is a still more ambitious scheme, which aims at avoiding the temperature limitations of (*a*) imposed by the structural properties of solid reacting materials. In it, the inert propellant and the nuclear "fuel" would each be injected into the chamber in a manner closely analogous to that employed on present liquid bi-propellant chemical rockets. In the chamber, mixing would take place in the gaseous phase, the size of the system, pressure and temperature of the gas, and concentration of fissile material, being such as to satisfy critical conditions for a chain reaction (see Fig. 4).

(*a*) Solid Reactor

In proceeding to a more detailed discussion of this type, we may begin by recalling that there are two main kinds of fission reaction, namely the "Fast" and the "Thermal."

In the former, the neutrons released in fission have time to make only one or two elastic scattering collisions before being absorbed in a nucleus or escaping from the system. The energy lost in the small number of scattering collisions will, in general, be a very small fraction of the original neutron energy (which will be greater than 1 Mev for most neutrons released in fission). Consequently, the energy of the neutrons will be high throughout their careers and their average life between release and final capture or escape is extremely short ($\simeq 10^{-8}$ secs.).

In the thermal reaction, however, the system contains only a small concentration of fissile material mixed with a large concentration of so-called moderating material. The nuclei of the moderator are very light and therefore effective in reducing the neutron energy by elastic scattering collisions. Furthermore, the relative probability of a neutron being captured by a nucleus is made so small, compared with the probability of scattering collisions, that it is able to make a very large number of the latter while avoiding capture. Consequently, the neutron loses nearly all its initial energy and comes into thermal equilibrium with the surrounding medium. In this state, it diffuses through the system until finally it is captured or it escapes from the reactor surface. Its life during all this process may be of the order of a millisecond.

Either of these two sorts of fission reaction might theoretically be utilized in a solid reactor for rocket propulsion. The fast reaction is the basis of the atomic bomb and—as pointed out in Part I of this series—there can obviously be no question whatsoever of employing any explosive or uncontrolled process. However, it *is* possible to control a fast neutron system, though such an aim presents peculiarly difficult problems of mechanical design at the operating temperatures necessary for the rocket application; the fissile material which would have to be manipulated for control would be particularly exposed to the hot propellant gas stream. Probably the reacting material would be divided into a large section just sub-critical, and a small section, controllable in position, which would be used to bring the system just a safe amount above criticality when the combined masses were close together. The multiplication constant would then be just above unity when *delayed neutrons* were taken into account, but just below unity when only *prompt neutrons* were considered (*cf.* reference 3); such a system could probably be made fairly safe against sudden rises of neutron density or fission rate. Apart from the control problem, a disadvantage of the fast reactor would be the greater number of fast neutrons escaping from its surface to accentuate the radiation shielding problem, but in spite of these conditions, its much more favourable conditions of mass and compactness would constitute a strong argument for preferring it to the thermal type.

The Smyth Report[4] places the critical mass of U^{235} in the region 2 to 100 kg. and no authoritative statement has yet been published giving a better value. Peierls[9] has given a simplified method of calculating the critical radius (a) of a sphere, assuming that there are only two processes (viz. elastic scattering and capture) occurring; according to this:—*

$$a = [(0{\cdot}552\zeta + 0{\cdot}216\zeta^2)\beta]^{-1} \quad \ldots\ldots\ldots\ldots\ldots\ldots (III.1)$$

* NOTE.—Certain symbols are ascribed a different meaning in this section as compared with preceding ones.

where:—

$$\zeta^2 = 1 - \alpha/\beta$$
$$\alpha = N(\sigma_s + \sigma_f)$$
$$\beta = N(\sigma_s + \nu.\sigma_f)$$

Here we have assumed only fissile material to be present and no non-fission capture. σ_s is the nuclear scattering cross-section of the material and σ_f the fission cross-section (both in cm.^{2}), while N is the number of nuclei per cm.^{3}

ν is the number of neutrons produced per fission, which, according to the German atomic energy workers[5] had an average value of 2·0.

σ_s is not published for U^{235} or other fissile nuclei, but heavy nuclei of comparable mass have values in the region of 6–8 barns (1 barn = 10^{-24} cm.^{2}), hence we may assume a figure of about 7×10^{-24} cm.^{2} to be reasonable.

σ_f for fast neutrons should be about the same as the geometrical cross-section, according to the classic pre-war paper of Bohr and Wheeler. This will be about $2{\cdot}5 \times 10^{-24}$ cm.^{2}

In solid uranium (density = 18 grm./cm.^{3}) N will be $4{\cdot}5 \times 10^{22}$ nuclei per cm.^{3} giving:—

$$a = 6{\cdot}4 \text{ cm.}$$

The weight of such a sphere would be abont 20 kg., a value which must be taken as an order of magnitude rather than an accurate estimate.

Such a solid mass would, of course, be useless in practice, since it would not present anything like the necessary surface area for the huge heat transfer required to take place. It would therefore be necessary to provide elaborate honeycombing of the reactor, or to subdivide the fissile material into minute beads, to produce the required surface. The mass of fissile material required would itself be increased in consequence, but the most important effect would be that its more diffuse distribution would make the reactor a very tenuous affair, the mean density of which might be only a tenth of that of its solid matter. (The critical radius would increase by a similar factor, while the critical mass would increase inversely as the square of the mean density of fissile material present.) In a tenuous system, there would always be a danger of mechanical collapse, so changing the critical conditions as to produce a violent rise in the neutron multiplication rate and a consequent explosion; it *might* be argued, however, that such mechanical collapse would probably result in the loss of the rocket in any case, whether a "soft" atomic explosion occurred or not. (It is worth pointing out in passing that such an explosion, while catastrophic, would not have the full force of that from an atomic bomb, since the increase in reaction rate would not occur with sufficient rapidity.)

Still considering the solid reactor, the alternative to the fast reaction is the thermal one, in which (as we have said) the neutrons are slowed down to thermal energies, by a great mass of moderating material, before their final capture. Such a system might have the virtues of greater safety and ease of mechanical (control) and structural design, but it would certainly also have a much greater size and weight to offset these attractions. The reduction in its required weight of shielding would represent only a very minor compensation of its severe disadvantages in bulk. As a very rough guess, the fast reactor might

weigh between 1 and 10 tonnes, whereas the thermal type might attain over 50 tonnes; a consequence of any excessive reactor weight, of course, would be a poor mass ratio for the whole rocket. If the mass ratios for ships with atomic drive were notably worse than those for ones using chemical motors, then much higher exhaust velocities would be demanded from the nuclear power plants before they could even equal the performance of their chemical competitors. However, even 50 tonnes reactor weight might be acceptable on very large rockets weighing many hundred tonnes; the reactor weight would increase only very slowly with thrust output.

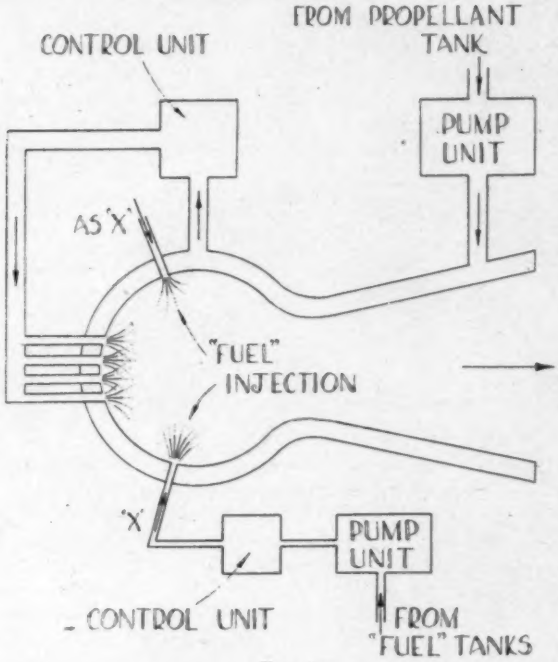


FIG. 4.
Schematic Diagram of Motor using possible "Gaseous" Reacting System.

The career of any neutron in a thermal reactor, from the instant of its release to the time of its final capture, can be divided into two parts, viz.

(i) The *slowing down period*, during which the average neutron traverses a distance from its point of origin which is represented by the *slowing down length*, L_s.

(ii) The *diffusion period* during which, after being slowed down to thermal energies, the neutron diffuses through the medium. The distance traversed by the neutron, from the point at which it becomes thermal

to the point where it is captured, is represented by the *diffusion length*, L_D.

This is a rather idealized picture, since it envisages the neutron becoming thermal quite suddenly, whereas in fact the energy at which this occurs is a very indefinite quantity; the assumption, however, does not lead to any appreciable inaccuracies.

The quantity L_M given by the expression:—

$$L_M^2 = L_S^2 + L_D^2$$

is known as the *migration length* of the system, and represents the total distance traversed by the neutron.

The neutron multiplication in fission has to balance the loss of neutrons from the surface of the system, *and* the loss of neutrons by capture in the nuclei of the moderator and any other non-fissile material present. Let us write η for the number of fresh neutrons produced for each neutron captured; then η is related to ν (the number of neutrons per fission) by the expression:—

$$\frac{\eta}{\nu} = \frac{\text{Probability of fission capture}}{\text{Total probability of any capture}}$$

This ratio will depend on the concentration of fissile material.

According to the diffusion theory,[6] it can be shown that the critical radius of a spherical reactor is given approximately by:—

$$a = \frac{\pi L_M}{\sqrt{\eta - 1}} \times f\left(\frac{L_S}{L_D}\right) \quad \text{.....(III.2)}$$

where $f\left(\frac{L_S}{L_D}\right)$ is a function always having a value close to the unity which we shall assume in the following.

Since our reactor has to run at a very high temperature, it will be necessary to select the moderator for its refractory properties as well as from considerations of low atomic weight; the choice will probably lie between some substance such as carbon or a refractory compound or alloy of beryllium. Boron and lithium compounds would be unusable because of the great capture cross-sections of their nuclei for thermal neutrons. Let us assume carbon as the moderator; the value of L_S will depend on the initial energy of the neutrons released in fission. For a neutron slowing down from 2 million electron volts to 1 electron volt, L_S in carbon of density 1·6 grm./cm.^{3} is given by Marshak[7] as being very nearly 18 cm. This agrees well with the observed value for fission neutrons which has been given by Fermi[10] as 17·3 cm.

The value of L_D will depend on the concentration of fissile material; if there were none present, so that all the neutron capture took place in carbon nuclei, the diffusion length would be about 50 cm. If there were sufficient fissile nuclei to produce a 90 per cent. probability of capture by them, then L_D would be decreased to about 16 cm.; with $L_S = 18$ cm. this would make $L_M = 24$ cm.

Assuming $\nu = 2{\cdot}0$ as before, we should have $\eta = 2{\cdot}0 \times 90$ per cent. $= 1{\cdot}8$, and from equation (III. 2) can now obtain the value of the critical radius:—

$$a = 85 \text{ cm.}$$

Once again (as for the fast reactor) we should need to provide a honeycombed, or finely divided, system in order to obtain the necessary surface for heat transfer, hence the practical value of reactor radius would be much larger than this. The effect could be represented by assuming a mean density (in grm./cm.^{3}) for the whole reactor $= \rho$, in comparison with the value of 1·6 for the solid carbon moderator of which it would mostly be comprised. From the same laws as were stated when discussing the similar problem on the fast reactor, we should then have:—

$$a = \frac{1{\cdot}6 \times 85}{\rho} = \frac{135}{\rho} \text{ cm.}$$

while the total mass of a system to attain criticality would be of the order of $\frac{10}{\rho^2}$ tonnes (since the mass of the minimum 85 cm. radius system, largely composed of carbon at 1·6 grm./cm.^{3} would be about 4 tonnes).

Obviously, one would endeavour to keep ρ as large as possible, though of course such a trend is opposed to the need for ample throughway and heat exchange areas. Probably the best result would follow from a scheme in which the moderating regions were kept comparatively solid and the fissile ones finely subdivided; under such circumstances ρ might lie between one half and one third, giving a weight of 40–100 tonnes.

Some factors must now be listed which make the development of *any* form of solid reactor, for incorporation in a rocket motor, an extremely formidable task.

(i) Reference has already been made to the need for providing ample surface for heat interchange between reactor and propellant; something like 10^8 or 10^9 cm.^{2} might be necessary, as the required transfer might be of the order of 10^7 kilocalories/sec. While this would be perfectly feasible in theory, the practical problems involved are great and data for their exact evaluation are probably lacking at the present time.

(ii) One of the practical problems associated with (i) is the fact that, unless the reactor were to assume impossible overall dimensions, the provision of the necessary interface area would involve forcing the propellant gas through long narrow passages. Such a restricted throughway would imply large pressure drops across the reactor, due to the huge propellant mass flow; this in turn would imply severe stresses on the structure and very large values of the pumping power required. The reactor weights quoted earlier in this paper referred to the bare reactor less enclosing chamber and nozzle, ancillary equipment for pumping and injection, etc.; it is easy to see that prohibitive power absorptions in the latter units could possibly make the whole scheme impracticable. Compared with rocket motors, the specific weight of rotating machinery such as pumps and turbines (i.e. related to their power rating) is very large.

(iii) Most fundamental and obvious of all the difficulties is the temperature one; under normal conditions of heat exchange, the reactor would need to be hotter than the propellant gas—the lower this temperature

differential, the more severe problems (i) and (ii) would become. Even with propellants of the lowest possible molecular weight, we have seen that chamber gas temperatures of *at least* 3,000° K. will be necessary before the atomic motor can show worthwhile increases in performance over what may be possible with future chemical fuels. There are few materials which even remain solid in this region, let alone provide any appreciable mechanical strength. Uranium melts at 1,150° K., though the fissile material could actually be used in a refractory form (M.P. for uranium oxide is 2,100° K.). Even the carbon moderator would undergo sublimation at about 3,500° K. Some consolation may be obtained from recalling that not all the reactor need be at the maximum temperature; by suitable design, it might be possible to arrange for the cooler parts to provide adequate strength. Further, it might even be permissible to allow the hottest regions to erode or even to vaporize slowly, providing that the amount of material so lost during the running period did not prove excessive.

Even so, the outlook does not look very promising, especially since the mechanical properties of the reactor materials may be still further reduced by the disruptive action of the high energy nuclear particles.

If we are to hold out any hope for the successful development of a solid reactor operating at useful temperatures (for the rocket application), we must look to three things. Firstly, to very ingenious mechanical and structural design. Secondly, the development of alloys and compounds of fissile (and other) materials with extremely good refractory properties. Thirdly, some improvement over conventional methods of heat transfer, whereby the gas temperature could approach or even surpass that of the reactor itself. This latter object might be achieved if the propellant gas did not attain true thermal equilibrium while traversing the reactor; if the solid nuclear fuel were distributed in thin layers, an appreciable fraction of the energy of the recoiling fission fragments might be directly absorbed in producing excessive dissociation and ionization in the propellant gas. (Such effects were briefly discussed in Section 4 of Part II, in connection with their influence on γ.) If the recombination times were larger than the time of passage through the reactor, then the gas would subsequently reach a higher temperature than the reactor; however, the high pressures needed for efficient operation would, it must be noted, tend to reduce the re-combination times.

(*b*) Gaseous Reactor

Even on superficial consideration, it is apparent that this type offers considerable promise of avoiding the disadvantages of the solid reactor. The nuclear fuel and the propellant are intimately mixed in a chamber, under turbulent conditions ideal for heat transfer, and there are no constricted throughway passages to impose excessive back-pressures. Above all, the operating temperature is limited by the requirements of the chamber walls (which can, and of course would, be cooled to lower temperatures than the gas), instead of by the demands of a solid reactor, some of the materials of which cannot be freely chosen, and which must probably be *hotter* than the gas.

However, as the following discussion will show, the gaseous system solves these problems only to introduce new and even more difficult ones of its own. The stronger radio-activity of its exhaust is an obvious disadvantage, and its controllability for safe operation is another. The latter difficulty would have to be met by metering the quantity of nuclear fuel admitted to the chamber, and could probably be surmounted; the nuclear fuel itself would have to be stored before consumption in various containers so disposed as to form a non-divergent (or sub-critical) system. The fuel to be fed into the chamber might be in powdered form, either by itself or in some liquid suspension, or it might take the form of a wire to be extruded into the chamber, or again (and more probably) it might be a liquid compound of fissile matter. Apart from all these problems, however, there are others of a more fundamental character.

The conditions for a self-sustaining chain reaction in a gaseous system would be determined by five parameters, viz.

(i) Chamber temperature (θ_c, °K.).

(ii) Chamber pressure (P_c, standard atmospheres).

(iii) Size of the system, say, radius of spherical chamber (a, *metres*).

(iv) Concentration of nuclear fuel relative to propellant (k, $= \frac{m_f}{m_p}$ in Part I).

(v) Physical (nuclear) properties of both propellant and fuel.

It is important to note that the gaseous reactor would operate on the *thermal* (slow neutron) system, due to the relatively small proportion of fissile nuclei to propellant nuclei, the latter acting as a moderator. At least, this would be true for any reasonable mixture, since the amount of fuel needed to supply the necessary energy to the propellant mass is very small. Hence, in the gaseous reactor, we have to consider very carefully the absorption of neutrons in the inert propellant nuclei; this was unnecessary on the solid type, since there we had a fixed quantity of fuel "frozen" in the reactor and its concentration relative to the propellant at any instant could be made large enough to render neutron capture by the propellant unimportant. Here, however, we are ejecting fuel with the propellant and it is, therefore, most desirable that its proportion should be relatively very small, giving a great preponderance of propellant nuclei.

Now, suppose we have:—

N_f fuel nuclei per cm.^{3}

N_p propellant nuclei per cm.^{3}

and that for thermal neutrons at temperature θ*:—

$\sigma_f(\theta)$ is the fission cross-section for the fuel nucleus;

$\sigma_p(\theta)$ is the capture cross-section for the propellant nucleus.

* These cross sections will be energy dependent, i.e. will depend on the temperature θ of the thermal neutrons.

The mean free path of a neutron for fission (i.e. the average length of path it would have to traverse before capture by a fissile nucleus) would then be given by:—

$$l_f(\theta) = \frac{1}{N_f.\sigma_f(\theta)}$$

where $\sigma_f(\theta)$ is in cm.^{2} and $l_f\ (\theta)$ in cm. Similarly, the mean free path of a neutron for capture by a propellant nucleus is given by:—

$$l_p(\theta) = \frac{1}{N_p.\sigma_p(\theta)}$$

while the net capture mean free path is defined as:—

$$l_c = \frac{l_f\, l_p}{l_f + l_p}$$

The relative probability of capture by a fuel nucleus will be given by *either* of the ratios*:—

$$\frac{N_f\sigma_f}{N_p\sigma_p + N_f\sigma_f} \quad \text{or} \quad \frac{l_p}{l_f + l_p}$$

Hence, it is desirable that $N_f\sigma_f \gg N_p\sigma_p$ or $l_p \gg l_f$, otherwise far too many neutrons will be lost to the propellant. In fact, one can see quite easily that:—

$$\eta = \frac{N_f\sigma_f}{N_f\sigma_f + N_p\sigma_p}.\nu$$

where η and ν are the neutron multiplication factor and the number of neutrons per fission as before.

For a self-sustaining reaction, $\eta \geqslant 1$; the limiting case of $\eta = 1$ is academic insofar as it leads to an infinite size of system. It will be more convenient to use the partial densities of propellant (ρ_p) and fuel (ρ_f) rather than concentrations of nuclei, since the partial densities give the relative masses of the two materials going through the system. With symbols as already defined, plus A_f and A_p for the atomic weights of fuel and propellant respectively, we then have:—

$$k = \frac{m_f}{m_p} = \frac{\rho_f}{\rho_p} = \frac{N_f A_f}{N_p A_p}$$

This leads to the relationship:—

$$k\left(\frac{\nu - \eta}{\eta}\right) = \frac{A_f\sigma_p}{A_p\sigma_f} \qquad \text{.....(III.3)}$$

The value of k found from (III. 3) for the limiting case of $\eta = 1$ will be written as $k_{\min}$; that is, for a self-sustaining system of finite size, where $\eta > 1$, the actual $k > k_{\min}$.

* The (θ) can be dropped from the cross-sections, etc., when ratios are involved, since both σ_f and σ_p may be assumed to vary as $\frac{1}{\sqrt{\theta}}$.

Now, A_f will vary from 233 to 239, and may be taken as a round figure of 240.

There is no published information on σ_f for Pu^{239} or U^{233}, while for U^{235} there exist only pre-war data apart from figures given by Bothe.[5] Since the latter were obtained more recently (by von Droste, during the war, on the German Uranium Project), they will be used here. According to this source, σ_f (thermal) is 3·6 barns for the *average* uranium atom (99·3 per cent. U^{238}, 0·7 per cent. U^{235}); since only the U^{235} is fissile at thermal energies this gives:—

$$\sigma_f = \frac{3{\cdot}6 \times 100}{0{\cdot}7} \times 10^{-24} \text{ cm.}^2$$

$\simeq 510 \times 10^{-24}$ cm.^{2} (At an arbitrary temperature of about 300° K., which will be used for comparative purposes below; remember that σ_f and σ_p both vary as $\frac{1}{\sqrt{\theta}}$).

Hence, $\frac{A_f}{\sigma_f} \simeq 5 \times 10^{23}$. Table V following gives data for various propellants (at the assumed comparison temperature of 300° K.); where the propellant is a compound, the data refer to the molecule, e.g. σ_p is then obtained by adding the cross-sections for individual atoms. The value of ν has been taken as 2·0 as before, and k_{min} is hence also tabulated.

TABLE V

Propellant	σ_p (barns)	$\frac{A_p}{\sigma_p}$	k_{min}
Hydrogen H^1	0·27	3·7*	$1{\cdot}3 \times 10^{-1}$*
Deuterium H^2 or D	0·0005	4,000*	$1{\cdot}2 \times 10^{-4}$*
Helium He	negligible	very great	very small
Ammonia NH_3	2·1	8·1	$3{\cdot}1 \times 10^{-2}$
,, $N^{15}D_3$	<0·01	>2,000	$<2{\cdot}4 \times 10^{-4}$
Steam H_2O	0·54	33	$1{\cdot}5 \times 10^{-2}$
,, D_2O	0·001	20,000	$2{\cdot}4 \times 10^{-5}$

(* Values are the same for di-atomic or mon-atomic forms, since σ_p and "A_p" are both doubled for the di-atomic molecule.)

It will be remembered that there is another minimum value of k set by energy considerations (see Table II in Part I); this value is about 10^{-6} for a reasonably efficient unit with 10 km./sec. exhaust velocity. It is clear from Table V that the gaseous reactor cannot function at all with k values anything like as low as those demanded from purely energy considerations. Propellants involving hydrogen or natural nitrogen (mainly N^{14}) would require many thousand times the amount of nuclear fuel which ought to suffice; for deuterium and deuterium compounds, this factor of waste would be only of the order of a hundred or so, so these substances cannot be rejected purely on a basis of economy in nuclear fuel.

In passing, it may be noted that even for the more wasteful propellants, the assumption made in Section 4 of Part II—to the effect that only the propellant molecular weight (M) was thermodynamically significant—is still valid. If the molecular weight of the nuclear fuel is denoted by M_f, and the true average value of the exhaust gas complex by $\overline{M}$, then:—

$$\overline{M} = \frac{1 + k}{1 + \frac{M}{\overline{M_f} \cdot k}} \cdot M$$

The ratio $\frac{M}{\overline{M_f}}$ is of the order of 10^{-2}, hence $\overline{M} \simeq M$ even for k values greatly exceeding those necessary from purely energy considerations.

We must now consider the physical size of a possible gaseous reacting system; assuming this to be of spherical shape, the critical radius can be derived in terms of the migration length L_M for the neutrons, using the same relationship as for the solid reactor. The various characteristic lengths involved, however, will here be proportional to $\frac{1}{\rho}$ where ρ is the gas density in the chamber. Thus, we must find expressions for:—

(i) The diffusion length at unit gas density, ρL_D.

(ii) The slowing-down length at unit gas density, ρL_s.

It can be shown that the first quantity is given by the approximate relation

$$\rho L_D(\theta) \simeq \frac{A_p}{\sqrt{\sigma_s(\theta) \cdot \sigma_c(\theta) \cdot (1 - b)}}$$

where $\sigma_s(\theta)$ is the mean scattering cross-section, and can be taken without much loss of accuracy to be the cross-section of a propellant nucleus for thermal neutrons at temperature θ. b is the mean cosine of the angle of scattering of a neutron when it makes an elastic collision, and this can be shown to be equal to $\frac{2}{3} A_p$.

The quantity $\sigma_c(\theta)$ is the mean capture cross section of the thermal neutrons, taking into account both capture in the propellant and fissile capture in the fuel. It can be shown that:—

$$\sigma_c(\theta) = \sqrt{\frac{300}{\theta}} \left(\frac{x}{\nu - 1} + 1 \right) \sigma_p, \text{ barns}$$

where σ_p is the thermal neutron capture cross-section which is normally quoted for the propellant substance (i.e. at the arbitrary temperature of 300° K.) and where x is the concentration of nuclear fuel in the chamber relative to the minimum required for a chain-reacting system, i.e. $x = \frac{k}{k_{min.}}$ It may be noted that the quantity η, again assuming $\nu = 2{\cdot}0$, is related to x by the expression:—

$$\eta = \frac{2x}{1 + x}$$

Thus, we find that:—

$$\rho^2 L_D^2 = \frac{A_p^2 \sqrt{\theta}}{\sqrt{300}\,(1-b)(1+x)\sigma_s(\theta)\cdot\sigma_p}$$

For *hydrogen*, σ_s (5,000° K.) $\simeq$ 21 barns, and does not vary much from this figure over the temperature range interesting to us. Inserting this and other appropriate values (and unit constants), we get:—

$$\rho^2 L_D^2 = \frac{\sqrt{\theta}}{33(1+x)}, \text{ grm.}^2\,\text{cm.}^{-4}$$

For *deuterium*, with $\sigma_s \simeq 3{\cdot}5$ barns over a wide range, we get:—

$$\rho^2 L_D^2 = \frac{200\sqrt{\theta}}{(1+x)}, \text{ grm.}^2\,\text{cm.}^{-4}.$$

We observe at once that the diffusion length in deuterium is very much greater than for hydrogen, for the same values of ρ and x.

The theory for calculating the slowing-down lengths has been given in detail by Marshak,[7] who also calculates L_s for several substances assuming various initial and final neutron energies. It may be assumed that the final energy is 1 electron volt in the thermal state (strictly, this corresponds to 8,000° K, but little loss of accuracy is incurred by assuming the same value for temperatures of 3,000 to 5,000° K.). We saw that the theoretical value for slowing down length in carbon for a 2 Mev neutron going to lev agreed very well with Fermi's value for fission neutrons, so may assume the same end points for other media; we find the following values when we do so:—

$$\text{Hydrogen: } \rho^2 L_s^2 = 0{\cdot}50\ \text{grm.}^2\,\text{cm.}^{-4}.$$
$$\text{Deuterium: } \rho^2 L_s^2 = 9\ \text{grm.}^2\,\text{cm.}^{-4}.$$

The corresponding migration lengths are:—

$$\text{Hydrogen: } \rho^2 L_M^2 = 0{\cdot}50 + \frac{\sqrt{\theta}}{33(1+x)}.$$

$$\text{Deuterium: } \rho^2 L_M^2 = 9 + \frac{200\sqrt{\theta}}{(1+x)}.$$

and so the critical radii of spherical systems (with $\theta = \theta_o$) are given by:—

$$\textit{Hydrogen}: \rho a_c = \pi \sqrt{\frac{x+1}{x-1}\left(0{\cdot}50 + \frac{\sqrt{\theta}}{33(1+x)}\right)}\ \text{grm. cm.}^{-2} \quad \text{(III. 4)}$$

$$\textit{Deuterium}: \rho a_c = \pi \sqrt{\frac{x+1}{x-1}\left(9 + \frac{200\sqrt{\theta_o}}{(1+x)}\right)}\ \text{grm. cm.}^{-2} \quad \text{(III. 5)}$$

Both expressions lead to prohibitive values of ρa_c; for example, taking $x = 2$ and $\theta_o = 5{,}000°$ K., we find:—

$$\text{Hydrogen: } \rho a_c = 6\ \text{grm. cm.}^{-2}.$$
$$\text{Deuterium: } \rho a_c = 380\ \text{grm. cm.}^{-2}.$$

Assuming the ideal gas laws to hold in the chamber, we have:—

$$\rho = \frac{MP_o}{82\theta_o}$$

where all these symbols have their former significance. Hence, for $\theta_o = 5{,}000°$ K. and P_o in standard atmospheres, we find (neglecting the effect of dissociation on M) that the previous results for $x = 2$ imply the following:—

Hydrogen: $P_o a_c = 12{,}000$ metre — atmospheres.

Deuterium: $P_o a_c = 400{,}000$ metre — atmospheres.

Clearly, this is a fantastic result; if we wished to limit our chamber pressure to even 100 atmospheres, we should need a chamber radius of 120 *metres for hydrogen* or 4,000 *metres for deuterium*. These results also indicate a rough order of magnitude for hydrogen or deuterium compounds, and other light elements give similar values. It will have been noted that the propellant giving greater economy in expenditure of nuclear fuel also gives the more impracticable chamber size.

Some reduction might be effected by using neutron reflecting walls to the chamber, but we know only of materials which act as diffuse reflectors, and it can be shown that the reduction in size brought about in this way would amount at the most to a factor of two. A greater reduction might be achieved by having fissile material *in* the walls and so forming a mixed solid-gaseous reactor; heat would then be generated in the walls, which would have to be cooled by the inflowing propellant. It would be found in practice that substantial reductions in size could be obtained only when the greater part of the heat was generated in the walls, in which case we should be back to the solid reactor more or less in its original form.

The alternative of having a small diameter chamber running at an immense pressure, in the region 10^5 atmospheres, must be ruled out unless the future brings quite startling improvements in available structural materials. Short of such a development, the only hope for the gaseous reactor would seem to lie in the discovery of some new nuclear reaction with very much more favourable critical conditions. The latter possibility, of course, cannot be ruled out.

The results obtained in this section for both solid and gaseous reactors are not very encouraging, and certainly support the recent remarks of Andrew Kalitinsky (Chief Engineer of the American N.E.P.A. Project), who said in a similar connection: "Such a development is by no means an easy one—nobody should expect to see an atomic rocket going to the moon this year or next." However, past experience teaches that one should never dismiss as impossible those results which appear to be removed from practicality even by a few orders of magnitude—only those which contravene some well-proven basic law. The nuclear powered rocket does not fall in this latter category, and there might be a case, in the fairly near future, for starting initial experiments, using a solid reactor at relatively modest temperatures. Possibly the fast type of reaction would be employed and hydrogen or ammonia used as propellant. It is unlikely that such early motors would show any very marked

improvement over chemical types, but it is only reasonable to suppose that work on them would bring increased knowledge and experience, leading in the end to greatly superior performance after an extensive period of research and development.

(To be continued.)

REFERENCES

A. *General.*

(3) *Science News*, No. 2. Various specialist authors, ed. R. E. Peierls and J. Enogat. Penguin Books, Ltd.

(4) *Atomic Energy*, by H. D. Smyth. H.M. Stationery Office.

B. *Technical.* (Ref. 8 covers all points in this section not specifically referred to 5, 6, 7, 9 and 10.)

(5) "Interrogation of Dr. Bothe." *C.I.O.S. Report* XXIX–47.

(6) "Elementary Approximations in the Theory of Diffusion of Neutrons," Wallace and Lecaine, *Montreal Report* MT. 12.

(7) "Slowing Down of Neutrons," Marshak, *Rev. Mod. Phys.*, July, 1947.

(8) *The Science and Engineering of Nuclear Power.* Various specialist authors, ed. C. Goodman. Addison-Wesley Press, Inc., Camb., Mass., U.S.A.

(9) "Critical Conditions in Neutron Multiplication," by R. Peierls. *Proc. Camb. Phil. Soc.*, **33**, 1939.

10) *Science*, 105, No. 2715, Jan. 10, 1947: E. Fermi.

ABSTRACTS

EDITED BY J. HUMPHRIES

Heat Transfer to Bodies Travelling at High Speed in the Upper Atmosphere

(J. R. Stalder and D. Jukoff. *J. Aero. Sci.*, July, 1948, Vol. 15, No. 7, pp. 381–91, graphs, refs.)

The high speed associated with flight at very high altitudes introduces many new problems to the missile designer. Not the least of these is overheating of the missile structure due to frictional heating. At the extreme altitudes encountered during flight of sounding rockets or missiles, the atmosphere can no longer be considered as a continuum, and account must be taken of the individual motions of the molecules comprising the atmosphere.

Using the methods of kinetic theory, calculations have been made of the temperature of uncooled flat plates travelling at high speed in the upper atmosphere. The calculation may be extended to bodies of arbitrary shape by considering them to be comprised of a number of flat plates. It is pointed out that an effective method of cooling is to ensure thermal contact between portions of the body inclined at positive and negative angles with respect to the flight path. The effect of solar radiation on body temperatures is shown to be increasingly important as the flight altitude increases.

Introduction to the Problem of Rocket-Powered Aircraft Performance

(H. Reese Ivey, E. N. Bowen and L. F. Oborny. *N.A.C.A. Tech. Note No.* 1401, December, 1947, 46 pp., diags., ref.)

An introduction to the problem of determining the fundamental limitations on the performance possibilities of rocket-powered aircraft is presented

Previous material on the subject is reviewed and given in condensed form along with supplementary analyses.

Some of the problems discussed are:—

(1) Limiting velocity of a rocket projectile.
(2) Limiting velocity of a rocket jet.
(3) Jet efficiency.
(4) Nozzle characteristics.
(5) Maximum attainable altitudes.
(6) Range.

Formulae are presented relating the performance of a rocket-powered aircraft to basic weight and nozzle dimensional parameters. The use of these formulae is illustrated by their application to the special case of a non-lifting rocket projectile.

Gypsum, or Modifications of Gypsum, as a Combustion Chamber Liner for Special Short-Term Rocket Motors

(J. A. Slyh *et al.* Three reports published by U.S. Dept. Comm., Off. Tech. Serv. at $1.00 each)

PBL 79492, December, 1946, 9 pp.; PBL 79493, January, 1947, 10 pp. Data to show resistance of specimens made from mixtures of plaster of paris and graphite to high temperatures.

PBL 79512, February, 1947, 10 pp. Data on preparation and test firing of a combustion-chamber liner, cast from a body composed of a mixture of plaster of paris and lampblack.

Refractory Oxides as Liners for Combustion Chambers of Rocket Motors

(J. A. Slyh *et al.* Two reports published by U.S. Dept. Comm., Off. Tech. Serv. at $1.00 each)

PBL 79496, February, 1947, 7 pp. Data to show effect of additions of small quantities of boric acid, chromic oxide, tantalum oxide, thorium oxide or vanadium oxide on the refractoriness and resistance to thermal shock of magnesia bodies.

PBL 79499, March, 1947, 9 pp. Data on thermal properties of several refractory oxides, bonded with a mixture of plaster of paris and graphite.

SECOND-HAND BOOKS ON PURE AND APPLIED SCIENCE

LARGE STOCK OF RECENT EDITIONS ALWAYS AVAILABLE.
BACK VOLUMES OF SCIENTIFIC JOURNALS OBTAINABLE.
OLD AND RARE SCIENTIFIC BOOKS IN STOCK.

LONDON: H. K. LEWIS & Co. LTD.
136 GOWER STREET, W.C.1. *Telephone: EUSton 4282 (5 lines).*

Other Papers Noted

Rocket Flight. A. V. Cleaver. *G.A.P.A.N. Jnl.*, Spring, 1948, Vol. 9, No. 1, pp. 21–4. A brief survey of the history of the rocket, its present-day applications and its possibilities for the future.

The Absorption-emission Pyrometer: a New Method for Measuring Flame Temperatures. Instruments, November, 1947, Vol. 20, No. 11, pp. 978–80, illus. Brief description of new pyrometer for measuring rocket exhaust gas temperatures up to 4,000° F. It is possible to record automatically and continuously the fluctuations in the temperature of the gases from a rocket motor as it starts up and runs.

Rocket. C. D. Schermuly, A. J. Schermuly and C. Schermuly. U.S. Patent No. 2,437,211, March 2nd, 1948. (Abs. in *Airplane Patent Digest*, March 15th, 1948, Vol. 19, No. 5, p. 83.) Solid propellant rocket.

XS-1: Design and Development. R. McLarren. *Aviation Week*, July 26th, 1948, Vol. 49, No. 4, pp. 22–4, 26–7, illus. A history of the development of the aircraft and description of its structure, motor and instrumentation. Very full information given.

REVIEWS

Principles of High-Speed Flight

(By H. McKinley Conway, Jr., Southeastern Research Inst., Tech. Publn. No. 471. 5009, Peachtree Road, Atlanta, Ga., U.S.A., $2.)

As Mr. Conway points out in his preface, most technical books fall into one of two categories: the simple primer for the layman, or the advanced treatise for the specialist. The volume under review falls into neither class, and in his attempt at a compromise for the benefit of "the engineer just poking into the subject of high-speed flight," the author has been relatively successful. One is allowed to poke, in the limited space of 140 typewritten pages, into the dark corners of such widely different subjects as aerology and wind-tunnel measurement, turbo-prop design and interplanetary travel.

Naturally, in so short a survey, much is left unsaid, and much said that must confound most readers in the absence of preamble, or of previous technical knowledge. This is particularly true of the mathematical discussion of compressible flow. Thus, one might have wished for more about swept wings: or one might complain of a lack of discreet restraint in dealing with such involved problems as those of intake and exit flow of gases in channels.

Each chapter is thoroughly up-to-date, and is rounded off with a good bibliography (if only NACA publications were more readily obtainable in this country!). The text is accurate; and the diagrams, if crude, are plentiful and well-chosen. Some of the data given seem of doubtful quality: for instance, the information on projectile drag seems unduly optimistic; and many would quarrel about the facile diagrams showing the rocket as a more suitable power-plant than the ramjet for very high speed aircraft.

Moreover, can we agree with the author that "in interplanetary travel there will be additional problems, including . . . boredom"? But those interested in the subject should not be bored if they read Mr. Conway's *Principles* en route.

T. N.

Breathing in Irrespirable Atmospheres

(By Robert H. Davis, Kt., F.R.S.A., Managing Director of Siebe, Gorman & Co., Ltd., with a Foreword by Professor Sir Leonard E. Hill, F.R.S., LL.D., M.B. Published by The Saint Catherine Press, Ltd., 29, Great Queen Street, Kingsway, London, W.C. Profusely illustrated. Price 25s. net.)

Summary of Contents.—A Short History of Gas and Incendiary Warfare from Early Times to the Present Day, The Physiology of Respiration, Breathing at High Altitudes, Resuscitation, The Evolution of Breathing Apparatus, Modern Gas Masks and other Respiratory Apparatus, Accounts of Some Mine Rescue and Recovery Operations, etc.

The science of astronautics embraces a plethora of subjects, but not all have received equal attention. For example, very little attempt has been made to obtain practical solutions to the problems associated with air and temperature conditioning a spaceship or a *spacesuit*. This is indeed a remarkable omission, for it is evident that ability to maintain a self-contained breatheable atmosphere over long periods is just as vital to the achievement of interplanetary travel as is ability to furnish a sufficiently potent drive for the vessel itself. For this reason alone the subject matter of *Breathing in Irrespirable Atmospheres* is a timely and useful—if unintentional—contribution to astronautics.

The firm of Siebe, Gorman will need no introduction to members of the British Interplanetary Society. Neither will the names of Sir Robert H. Davis and Sir Leonard E. Hill be unfamiliar to readers of this *Journal*. Whether the vacuum of space does, in fact, come within the category of an "irrespirable atmosphere" is perhaps a debatable point—yet probably for most practical purposes it can, in this connection, be so regarded. Certainly those of us who wish to learn something of the problems that have to be faced in furnishing a breatheable atmosphere during excursions through space and whilst abroad upon the surface of an airless body, will find much interest in the descriptions of various types of self-contained breathing apparatus which appear in this authoritative and fascinating book.

Since, above all, the atmosphere supplied to space-voyagers must be self-sufficient, and a closed-cycle method of regeneration highly desirable, the astronautical reader of this book should pay particular attention to the sections dealing with oxygen-evolving and regenerative systems.

Again, the pages devoted to a description of the original Haldane-Davis stratosphere flying suit should not be overlooked. For here, more clearly delineated than in any other type of dress, we begin to discern the lines of evolution of a spacesuit. Doubtless considerable improvements have been effected in stratosuits since the Haldane-Davis original, but relatively little information is at present publicly available. It is to be hoped that at some time in the future Sir Robert Davis will be able to amplify this section of his book to include an account of later versions of stratosuits—or even prototype spacesuits.

Although not a "textbook," *Breathing in Irrespirable Atmospheres* does, in fact, contain much material and data which can be used as a sound basis

for deeper consideration of the physiological demands that must be met in confined atmospheres and as a measure of the means that have been adopted to meet these demands under various conditions of operation. On the whole, it is probable that those who have been inclined to regard the question of supplying a spaceship with a breatheable atmosphere as merely a matter of taking "*x* square metres of pumpkin" or "a sixpenny packet of sunflower seeds," will be sadly and irrevocably disillusioned. If, indeed, our first space-voyagers are so crazy as to depart without adequate air and temperature conditioning equipment, then assuredly they will have occasion to recall this passage from the Rubáiyát of Omar Khayyám:

Some little talk awhile of Me and Thee
There was—and then no more of Thee and Me. H. E. R.

Observations of Mars and Its Canals

(By Harold B. Webb. Published by the author, 145, President Street, Lynbrook, Long Island, N.Y., U.S.A. 50 pp. 187 drawings. $2.)

This little book is the sequel to *Observations of the Planet Mars*, by the same author, printed in 1936, and repeats the object of the first by presenting a collection of drawings made by amateurs of the planet Mars. It has much to commend it.

Its 50 pages are filled with useful information of practical value, of the kind an inexperienced amateur such as the reviewer is always wanting but hardly ever finds in one spot, and never when needed!

Briefly it is a collection of 187 drawings made at the eye-piece by some twelve observers from all parts of the U.S.A. They cover, in the main, a period 1937 to 1939, thus including the interesting '39 opposition. They have been arranged in order of date by the author, H. B. Webb, who is, himself, one of the 12 observers.

Recorded under each of the drawings is the observer's name, the date and time of drawing, the size and type of instrument, and the magnification used.

Accompanying illustrations include maps of Mars on Mercator's Projection and photographs of Mars by L. J. Wilson.

General description by the author lubricates the collection, and in it are included interesting lists and tables of definite practical value. There is, for instance, a table of observers and the instruments used by them for the observtion of Mars for the past 50 years; another gives magnifications and sizes of instruments used by famous observers of Mars present and past.

Much information, incidentally, is derived from British Astronomical Association sources.

As to adverse criticism, very little of this can be levelled. There are, however, two moot points.

The first is that the whole book is printed in reproduced type-script. One would have thought that the fine quality of paper used in the book deserved a more suitable type-form. The second is a distinct impression that the reproduction of the drawings was not as good as the author might have wished.

However, its virtues far outweigh its failings. One feature, indeed, will give hesitating telescope-makers great heart—namely a collection of photographs of many of the instruments used for observing Mars by the contributors. A glance at some of them, and he will launch forth on the construction of an instrument of undoubted use, without feeling crushed and cowed by the scintillating complexity of the magnificent instruments which awe the pages of popular books of Astronomy! M. W. W.

L'Humanite devant la Navigation Interplanetaire

(By Albert Ducrocq. Published by Calmann Levy, 3, Rue Auber, Paris. 1947. 217 pp. 275 francs.)

This book does not deal solely, as its title would suggest, with the impact of interplanetary flight on human society, but is for the most part a popular treatise on space flight in general. The first three chapters deal with physical principles, design of a space-ship, and the physiology of the crew. The next two show the author to be particularly interested in Mars, and after further chapters on radar communication, and on other members of the solar system, his favourite planet returns as a background to his imaginative proposals for the future as expounded in the latter part of the book.

When the world's population reaches saturation point, M. Ducrocq asks, "who can believe that the nations will settle down to peace, seeking nothing, desiring nothing?" The road to Mars is his principal safety-valve, and this highway will be travelled by minor planets, or by Deimos and Phobos, diverted from their courses so as to pass near the Earth. The atmosphere of Mars will have to be artificially enriched with oxygen, and he follows C. S. Lewis in suggesting that the Martian "canals" might well be deep enough to hold a considerable atmospheric pressure at floor level.

An appendix deals with the use of atomic energy for space ships, but the author has not advanced beyond the unpractical idea of using the products of nuclear fission as a propellant. A. E. S.

Into the Atomic Age

(By Chapman Pincher, B.Sc. Hutchinson & Co. (Publishers), Ltd., 47, Princes Gate, S.W.7. 1948. Pp. 158. 9s. 6d.)

As scientific correspondent of the *Daily Express*, Mr. Pincher was largely responsible for organizing the Atomic Age exhibition sponsored by his paper last year. He reveals in this book that the Minister of Supply not only disapproved of that exhibition but asked that it should be abandoned. We can couple this information with the report that, of the 146,000 people who visited the atomic energy exhibition which toured Great Britain by train early this year, a large number were surprised to learn that atomic energy can be used for constructive purposes.

Official encouragement of such ignorance seems to derive from Foreign Office fear of offending the United States Government, which, Mr. Pincher

says, is vigorously opposed to all publicity on atomic energy. Their influence, he tells us, led to the cancellation of a proposed press visit to the Atomic Energy Establishment at Harwell, which is devoted to essentially peaceful research. Then, when Mr. Pincher found that it would be strictly legal to hover in a helicopter above the Harwell atomic pile, the Government foiled him again by putting the whole place under the Official Secrets Acts.

We are further reminded by this book that the Minister of Supply has power to confiscate any plans, drawings or research results relating to atomic energy from any person. So when you next make a sketch of your projected space-ship, beware of putting an atomic motor into it!

Remarking that Britain is now incapable of fierce competition with America in the peaceful applications of atomic energy, Mr. Pincher adds: "The geographical and industrial circumstances which led to the concentration of the Allied bomb effort in America will, in my opinion, turn out to be the biggest disaster that befell Britain in the last war."

Many other opinions of the author enliven his recital of the facts. For instance: "Whatever individual British scientists may say now about the use of the bomb being immoral, their work was originally directed at the production of atomic bombs, not merely to threaten the Germans, but to be used against them" (p. 129). The scientists might well reply that they were impelled by fear that the Germans might invent the bomb first; after all, the mere existence of poison gases on both sides was enough to deter their use.

The great ethical question whether the first bomb should not have been demonstrated to the Japanese over an uninhabited area, rather than at Hiroshima, will probably be debated for as long as civilization continues to be menaced by this outrageous invention. Here again, the author is not allowing the scientists to get away with it. Of 150 American scientists working on the Manhattan Project, he states, more than half, in reply to a poll, voted for "preliminary demonstration on a military objective."

He also says that the idea of demonstrating the bomb over an uninhabited place was ruled out, mainly because of shortage of atomic explosive, but also because the bomb might fail to explode. So many other reasons for this decision have been produced that their very multiplicity disinclines one to believe any of them. Of those known to the reviewer, one of the most interesting is Professor Einstein's suggestion, three years ago, that the Americans were in a hurry to end the Pacific war before Russia joined in.

Mr. Pincher has a strong complaint to make of the flippant attitude of the U.S. Task Force entrusted with the bomb explosions at Bikini, and of the "pantomime atmosphere" which prevailed and was afterwards mirrored in press reports of the terrifying results of the experiments.

So much for particular points. As for the book as a whole, it is a fairly comprehensive review of the many aspects of atomic energy, except that its use in reaction propulsion receives scanty mention. The author has done his best to turn a difficult subject into simple language, a task which inevitably involves an occasional departure from strict scientific accuracy. How well the author has avoided this pitfall, the more knowledgeable reader can judge for himself.

A. E. S.

The Inventor and his World

(By H. Stafford Hatfield. Published by Peguin Books, Ltd., in their "Pelican" Series. 256 pp. 1s. 6d.)

This cheap and revised edition of Dr. Hatfield's book, which first appeared in 1933, is a most readable and informative survey of the whole question of the relations between inventors and society. The author discusses the special creative qualities which distinguish true invention from the normal activities of routine design and development, and goes on to cover the practical problems of financing inventions, patent law, and the desirable and profitable trends of inventive effort.

Chapters on the various branches of invention (mechanical, electrical, chemical, etc.) deal with matters specifically related to these particular fields, while throughout are many interesting references to past history and suggestions of points which future inventors would do well to consider. Dr. Hatfield is an established chemist and physicist with many achievements to his credit, and is now one of the "Back Room Boys" of the Admiralty; his advice is therefore worthy of serious attention, more particularly since he obviously has a soft spot for that often strange and eccentric breed of men known as inventors, who have done so much to shape the modern world.

In Chapter XI ("The Transformation of Energy") he has this to say on the subject closest to the interests of this Society:—

"Rockets belong to this chapter, but I must refer the reader to the many accounts of their potentialities recently published. They offer the only means at present conceivable of escaping from this planet. Less ambitiously, we might hope, by gigantic efforts, to chuck an atomic bomb at the moon and watch the result through a telescope. The most hopeful thing about humanity, to my mind, is its support of completely non-utilitarian activities, such as giant telescopes, archæological research, Everest climbing, and so on. It may be that rocket development for fun and not for murder may receive great attention."

With the last two sentences especially, this reviewer, at least, feels much in sympathy.

A. V. C.

FORTHCOMING MEETINGS

February 9, 1949 (Wednesday). A lecture on "Interplanetary Flight" to the Royal Aircraft Establishment Technical Society, Farnborough, Hants, will be given by A. C. Clarke, 7.30 p.m. B.I.S. admission tickets (obtainable from the Secretary) may be used.

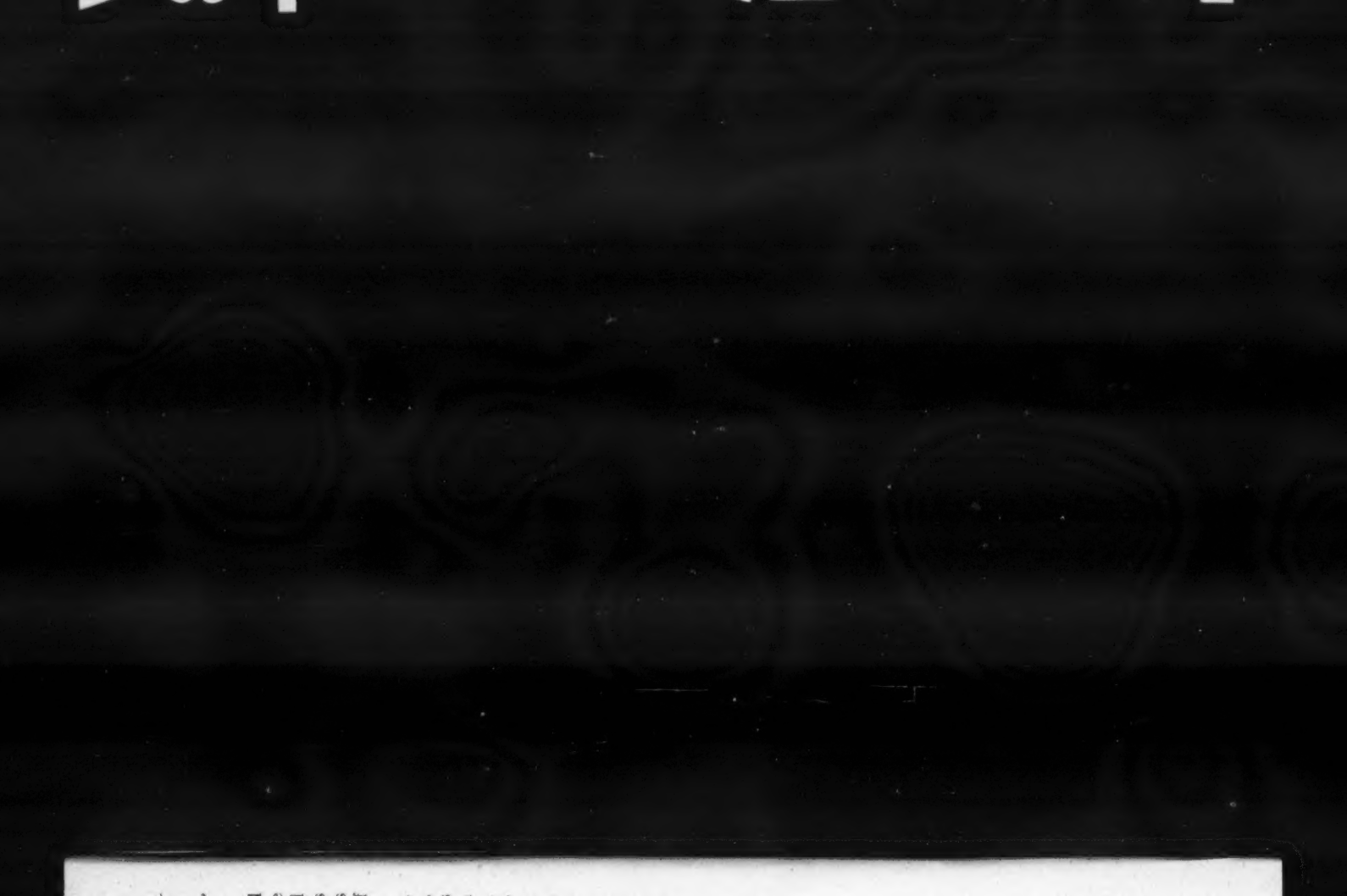
February 12, 1949 (Saturday). "The Design of Liquid-Propellant Rocket Motors" by J. Humphries. To the Society at St. Martin's School, 6 p.m.

February 22, 1949 (Tuesday). "Focus on the Moon," by Eric Burgess, to Stockport Photographic Society, Unity Hall, Greek Street, Stockport, Cheshire, 7.30 p.m.

March 12, 1949 (Saturday). "A Review of Progress in Astronautics since the War" by A. V. Cleaver. To the Society at St. Martin's School, 6 p.m.

March 15, 1949 (Tuesday). "Into Space" by Eric Burgess, Friends' Meeting House, Withens Lane, Wallasey, Ches., 7.30 p.m.

March 24, 1949 (Thursday). "Focus on the Moon" by Eric Burgess. To Manchester Astronomical Society, Reynolds Hall, College of Technology, Manchester, Lancs., 7.30 p.m.

April 2, 1949 (Saturday). "Astronautics and Astronomy" by M. W. Ovenden. To the Society at St. Martin's School, 6 p.m.

PRINTED BY W. HEFFER & SONS LTD., CAMBRIDGE, ENGLAND